Delft University of Technology

Document Version
Final published version

Licence
CC BY

Citation (APA)
Crul, M. R. M., Joore, P., Reijenga, J., & Diehl, J. C. (2026). *Medical Circular Living Labs Guidebook*. TU Delft OPEN Publishing. https://doi.org/10.59490/mt.271

Important note
To cite this publication, please use the final published version (if applicable).
Please check the document version above.

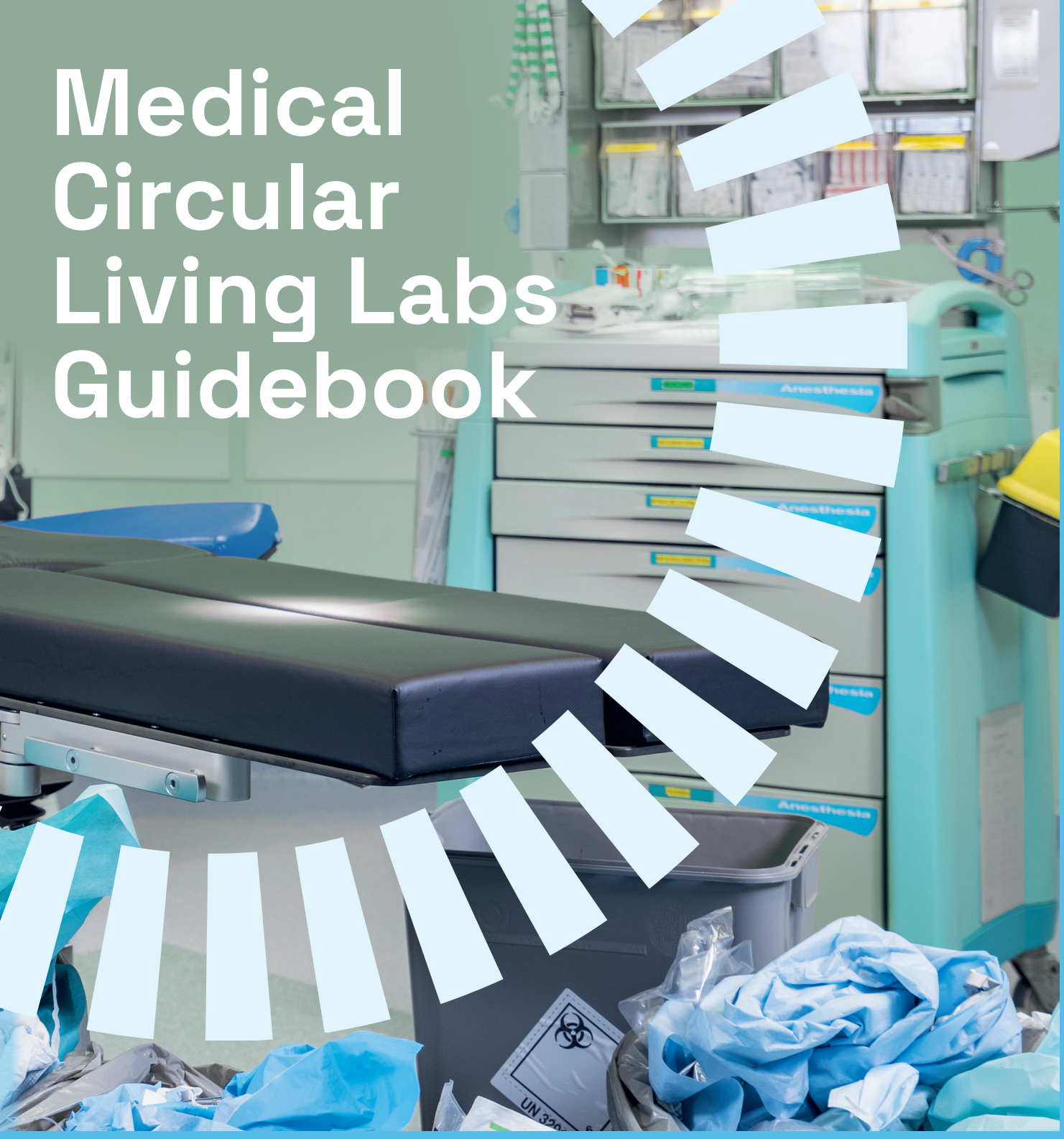
Copyright
In case the licence states “Dutch Copyright Act (Article 25fa)”, this publication was made available Green Open Access via the TU Delft Institutional Repository pursuant to Dutch Copyright Act (Article 25fa, the Taverne amendment). This provision does not affect copyright ownership.
Unless copyright is transferred by contract or statute, it remains with the copyright holder.

Sharing and reuse
Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

Takedown policy
Please contact us and provide details if you believe this document breaches copyrights.
We will remove access to the work immediately and investigate your claim.

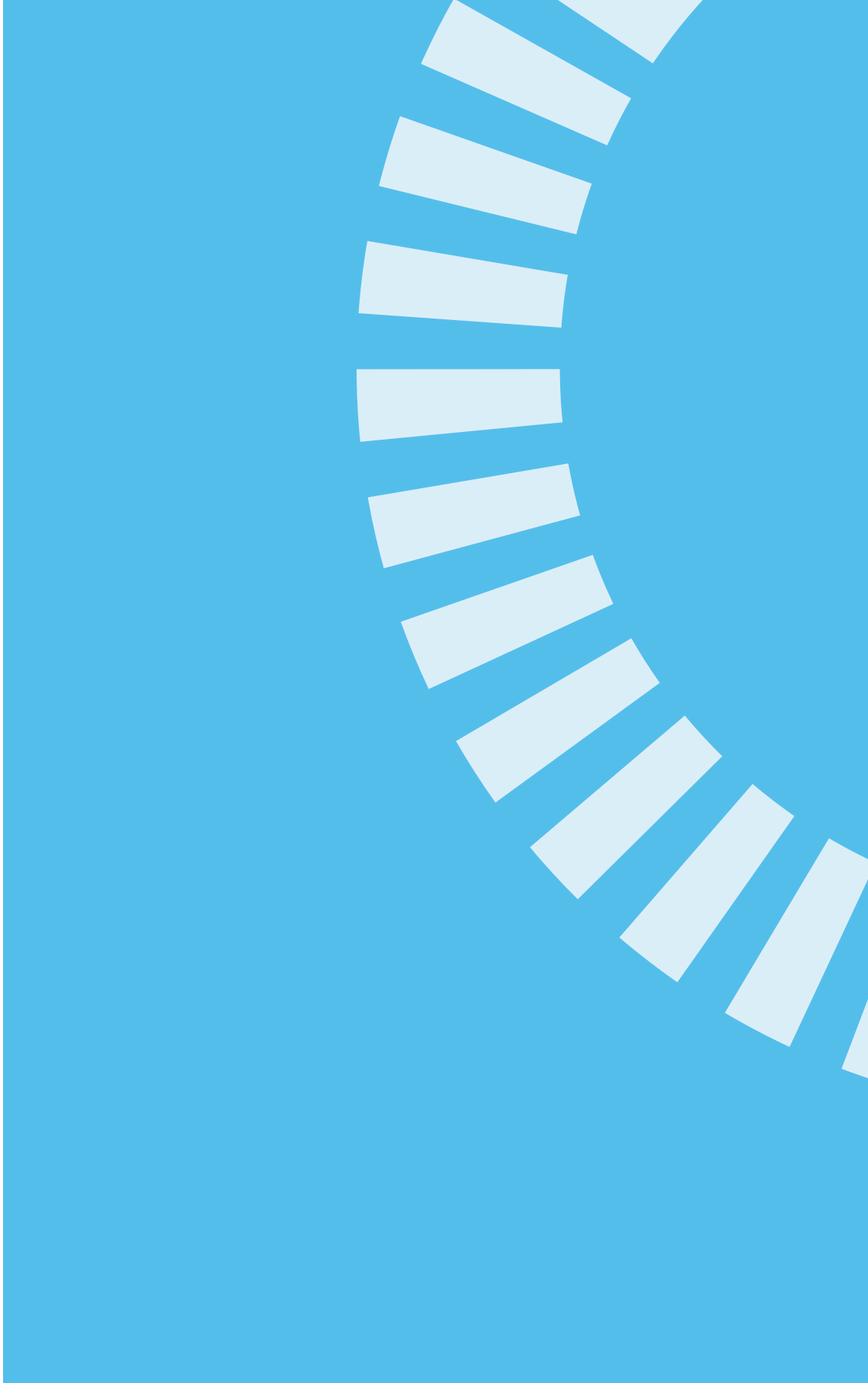
This work is downloaded from Delft University of Technology.

Medical Circular Living Labs Guidebook



TU Delft | OPEN Publishing

Marcel Crul, Peter Joore,
Johan Reijenga, Jan-Carel Diehl



Medical Circular Living Labs Guidebook

Marcel Crul, Peter Joore,
Johan Reijenga, Jan-Carel Diehl

esch-r
creating circular
hospitals together

TU Delft | OPEN Publishing

Colophon

Title: Medical Circular Living Labs Guidebook

Authors: Marcel Crul[1], Peter Joore[2], Johan Reijenga[3], Jan Carel Diehl[4]

1 Systemic Design Research Group, NHL Stenden University of Applied Sciences, The Netherlands, https://orcid.org/0000-0002-2873-2604

2 Systemic Design Research Group, NHL Stenden University of Applied Sciences, The Netherlands, peter.joore@nhlstenden.com, https://orcid.org/0000-0002-4585-008X

3 Business Innovation Research Centre, Rotterdam University of Applied Sciences, The Netherlands, a.j.reijenga@hr.nl, https://orcid.org/0009-0007-6707-9509

4 Department of Design for Sustainability, Faculty of Industrial Design Engineering, Delft University of Technology, The Netherlands, j.c.diehl@tudelft.nl, https://orcid.org/0000-0002-4007-2282

Keywords: medical living labs, circular living labs, healthcare innovation, circular design, systemic design

Publisher: TU Delft OPEN Publishing | Delft University of Technology, The Netherlands

Date: October 2026

DOI: https://doi.org/10.59490/mt.271

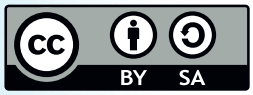
ISBN (online): 978-94-6518-456-2

ISBN (print): 978-94-6563-050-2

Layout: Studio RATATA

Illustrations: Marc Kolle

Cover photo: © Rogier Bos, 2026. All rights reserved. Reproduced with permission.
This image is excluded from the Creative Commons licence applying to the text in this book.



Copyright statement: This work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License (CC BY-SA 4.0). The Creative Commons licence applies to the text of this publication only. All photographs and illustrations are excluded from the licence unless explicitly stated otherwise. Permission for reuse must be obtained from the respective copyright holder. This publication builds upon the methodology presented in *The Urban Living Lab Way of Working Handbook* by Aranka Dijkstra and Peter Joore (2025), licensed under CC BY-SA 4.0. The methodology has been adapted and extended for application in healthcare and circular innovation. ©2026 published by TU Delft OPEN Publishing on behalf of the authors.

Electronic version: Electronic version of this book is available at: https://books.open.tudelft.nl

Funder information and grant number: This publication was developed as part of the research project ESCH-R: Evidence-based Strategies to create Circular Hospitals: Applying the 10-Rs framework to healthcare. The ESCH-R project is funded by the Netherlands Organisation for Scientific Research NWO as part of the Dutch Research Agenda NWA. File number NWA.1518.22.054. www.esch-r.org

Conflict of Interest: No conflict of interest to disclose.

Data Access Statement: This book presents guidance and practical insights derived from the ESCH-R project. No new research data were generated specifically for this publication. Where applicable, the underlying research data are managed within the ESCH-R project in accordance with the project's data management arrangements.

Use of AI: Generative AI (ChatGPT by OpenAI) was used to support text editing. Grammar and spelling checks were performed using digital language support tools. The authors critically reviewed, revised, and validated all generated outputs and retain full responsibility for the accuracy, interpretation, and final content of this publication.

Peer Review: This book has been peer reviewed. The peer review was open. The authors and the publisher would like to thank the reviewers for their time and effort.

Acknowledgements: The authors would like to thank the following individuals for their valuable insights, feedback, and contributions to the development of this handbook: Nicole Hunfeld, Jasper Klasen, Arjen Klink, Jotte de Koning, Ayşegül Özçelik, Jan Tsai, Antine Zijlstra, Maaike van Zuilen.

Disclaimer: Every attempt has been made to ensure the correct source of images and other potentially copyrighted material was ascertained, and that all materials included in this book have been attributed and used according to their license. If you believe that a portion of the material infringes someone else's copyright, please contact j.c.diehl@tudelft.nl.



Foreword



Photograph © Arie Kievit, 2026. All rights reserved. Reproduced with permission.
This image is excluded from the Creative Commons licence applying to the text in this book.

Foreword

Every day, healthcare professionals work tirelessly to improve and save lives. It is great to be part of a sector that has such a positive impact on people and society. At the same time, we are increasingly confronted with a difficult reality: healthcare itself has a significant environmental footprint. The materials we use and the products we discard contribute to resource depletion, waste generation, and climate change.

This creates an important challenge. How can we continue to provide the highest quality of care while reducing the environmental impact of the systems that support it? There are no simple answers. Healthcare is a complex environment where patient outcome and safety, infection prevention, regulations, logistics, procurement, and clinical practice are closely interconnected. Changing one part of the system often affects many others.

Over the past years, I have become convinced that addressing this challenge requires close collaboration across disciplines and organisations, a willingness to experiment, and the courage to rethink established ways of working. It also requires settings where new ideas can be developed, tested, and evaluated in real-world healthcare settings. This is where Medical Circular Living Labs can play an important role.

Within the ESCH-R project—Evidence-based Strategies to Create Circular Hospitals—we explore how circular innovation can be developed and implemented in practice. ESCH-R brings together hospitals, universities, industry partners, designers, researchers, healthcare professionals, and policymakers who share the ambition of creating a more sustainable healthcare system.

One of the most important lessons from ESCH-R is that meaningful change only happens when people learn and innovate together. Medical Circular Living Labs provide a setting where partners can together explore challenges, develop solutions, test them in practice, and learn from the results. In doing so, they help turn ambition into evidence-based action.

This guidebook builds on the knowledge and experiences developed within the ESCH-R consortium. It offers practical guidance for anyone interested in establishing a Medical Circular Living Lab. While the insights presented here originate from the ESCH-R context, we hope that the approach described in this publication will inspire and support hospitals and healthcare organisations across the Netherlands and beyond in developing their own circular innovation initiatives.

The transition towards circular healthcare will not be achieved by a single project or organisation. It requires a collective effort and a shared commitment to learning and innovation. I hope this guidebook contributes to that journey and helps create a healthcare system that is not only excellent in caring for people, but also responsible in its use of resources and its impact on the world on which our health ultimately depends.

I would like to thank all partners involved in ESCH-R for their commitment and contribution to this shared goal. Together, we demonstrate that circular healthcare is not merely an aspiration for the future, but something that happens today!

Dr. Nicole Hunfeld
Principal Investigator ESCH-R
Erasmus MC
Rotterdam, The Netherlands



Contents



Photograph by Jonathan Borba via Pexels. Used under the Pexels License.
This photograph is excluded from the Creative Commons licence applicable to the text of this book.

Contents

Foreword ____ 4
Chapter 1: Introduction and Reading Guide ____ 12
Chapter 2: Medical Circular Living Labs ____ 18
Chapter 3: When to Use Medical Circular Living Labs ____ 34
Chapter 4: Foundational Principles ____ 42
Chapter 5: Multi-Level Framework ____ 56
Chapter 6: Medical Circular Living Lab Process ____ 70
Step 1: Determine Circular Ambition ____ 80
Step 2: (Re)Design Medical Circular Living Lab ____ 88
Step 3: (Re)Design Circular Interventions ____ 94
Step 4: Test and Experience Interventions ____ 102
Step 5: Evaluate Interventions ____ 110
Step 6: Integrate and Contextualise ____ 116
Step 7: Learn from Experience ____ 122
Step 8: Monitor Systemic Impact ____ 130
Chapter 7: Coordinating a Medical Circular Living Lab ____ 140
Chapter 8: Conclusion and Glossary ____ 148
References ____ 156

Chapter 1

Introduction and Reading Guide





Photograph © Erasmus MC Rotterdam, 2026. All rights reserved. Reproduced with permission.
This image is excluded from the Creative Commons licence applying to the text in this book.

Medical Circular Living Labs Guidebook

This guidebook provides a practical and structured framework for establishing Medical Circular Living Labs (MCLLs). Grounded in a multilevel systemic design approach, the guidebook supports stakeholders in navigating the complex clinical, organisational, and regulatory contexts that shape circular innovation in healthcare.

In this publication we define an MCLL as a real-life research and innovation ecosystem, embedded in a hospital, where healthcare professionals, educational and academic partners, industry partners, and patients collaboratively co-create and test circular interventions that reduce the environmental impact of medical consumables, medical devices, value chains, and systems.

The guidebook presents an eight-step process that goes beyond conventional project planning, integrating stakeholder mapping, circular design strategies, iterative testing and validation, institutional learning, and coordination across various organisational and system levels. This approach ensures that innovations developed within MCLLs are not only technically feasible and clinically safe, but also strategically aligned, economically viable, socially accepted, and scalable within healthcare systems.

By functioning as both a design framework and a collaborative working guide, this guidebook can enable hospitals and their partners to establish MCLLs as engines for long-term, systemic circular transformation in healthcare.

This guidebook was developed as part of the ESCH-R project. However, the aim is for the MCLL approach to be suitable for use in other healthcare facilities as well.

Who Is This For?

This guidebook is intended for a broad group of stakeholders working to transform healthcare systems toward circularity and sustainability:

- Hospital/healthcare administrators, procurement professionals, and sustainability officers integrating circular goals into policy, governance, and operations.
- Medical staff—clinicians, nurses, allied healthcare professionals, and technicians—who are responsible for daily operations and need to implement and adapt circular innovations within daily care practices.
- Academic researchers, design teams, and students engaged in applied, interdisciplinary innovation focused on developing circular healthcare interventions.
- Industry partners, including medtech suppliers, waste processors, and material developers seeking co-creation and validation opportunities.
- Policymakers and funding bodies supporting structural and systemic innovation focused on green healthcare transitions within the healthcare sector.

Reading Guide

This guidebook is structured to guide the reader step by step through the development, implementation, and scaling of Medical Circular Living Labs (MCLLs), while also allowing different stakeholders to engage with the sections most relevant to their role. The chapters follow a logical progression, moving from conceptual understanding to practical application and, ultimately, to long-term integration within healthcare systems.

Chapter 1 introduces the purpose and scope of the guidebook. It positions MCLLs as a systemic approach to circular innovation in healthcare and provides an overview of how the guidebook is structured.

Chapter 2 provides the conceptual foundation, explaining the urgency of circularity in healthcare, outlining the need for systemic change, and introducing the concept of Medical Circular Living Labs. It presents key circular frameworks, such as the R-ladder and the Value Hill, and discusses the types of outcomes that can be expected from MCLLs.

Chapter 3 focuses on when to use an MCLL as an innovation approach. It situates MCLLs alongside other innovation approaches such as conventional research and development, simulation labs, and pilot projects. This helps the reader to determine under which conditions developing an MCLL is the most appropriate choice.

Chapter 4 describes the foundational principles that underpin the MCLL approach. These principles, such as co-creation, systems thinking, real-world experimentation, and continuous learning, define how MCLLs operate within complex healthcare environments and provide the mindset required for effective implementation.

Chapter 5 introduces the multi-level framework that explains how MCLLs connect different layers of the healthcare system, ranging from the broader innovation ecosystem to hospital departments and real-life experiments. This chapter clarifies how local interventions relate to system-level change.

Chapter 6 forms the operational core of the guidebook. It presents an eight-step, iterative process for establishing and running an MCLL, covering all phases from initiation and lab setup to co-creation, testing, evaluation, learning, and scaling. It also presents several key success factors and possible problems that should be taken into account.

Chapter 7 focuses on the coordination of an MCLL. It outlines what is required to manage such a complex, multi-stakeholder process, including the roles, responsibilities, and skills needed to ensure alignment between experimentation and long-term system change.

Chapter 8 concludes the guidebook by briefly reflecting on the broader significance of MCLLs as a mechanism for systemic circular transformation in healthcare and summarizing the key insights provided throughout the publication.This chapter also presents a glossary of key terms used throughout the publication, supporting a shared understanding among stakeholders.

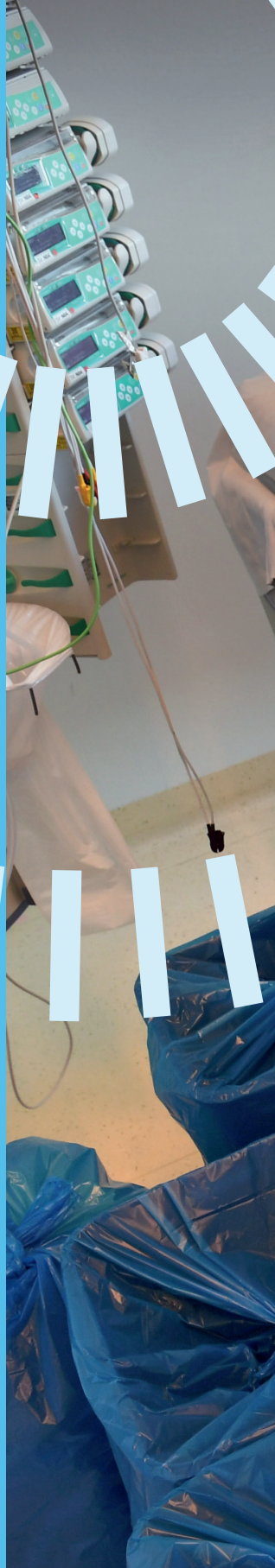
Using the Guidebook

Readers may follow this guidebook sequentially or navigate directly to the sections most relevant to their specific interest. While the chapters build from conceptual understanding to implementation and scaling, the guidebook is designed for flexible use, allowing readers to focus on specific parts while maintaining an overall view of how the elements are connected.

For hospital leadership, sustainability officers, and policy-level stakeholders, the guidebook primarily serves as a strategic resource. Chapters 3, 4 and 5 support decisions on when and how to position an MCLL within the broader healthcare system. Within Chapter 6, their focus will be mainly on Step 1 (initiation), Step 2 (creation), and the later phases of Step 6 (integration), Step 7 (learning), and Step 8 (monitoring and scaling). These sections help align MCLLs with organisational strategy, policy, and long-term system change.

For researchers, designers, clinicians, students, and industry partners, the guidebook functions mainly as an operational framework. Chapter 4 and 5 provide guiding principles, while Chapters 6 and 7 offer practical support for implementation. Within chapter 6, Step 3 (development), Step 4 (testing), and Step 5 (evaluation) are central, supported by Steps 6 to 8 for reflection, learning, and scaling. These sections guide co-creation, experimentation, and validation in real clinical settings. Also, Chapter 7 on coordination of the MCLL is relevant for this group.

Across all groups, the guidebook connects the conceptual foundation in Chapters 2 and 4 with the multi-level perspective of Chapter 5 and the practical process in Chapter 6. Readers new to the topic are advised to begin with Chapter 2, while those involved in implementation can use Chapter 6 as their main reference and consult other chapters as needed.



Chapter 2
Medical Circular Living Labs



Photograph © Marcel van den Bergh, 2026. All rights reserved. Reproduced with permission.
This image is excluded from the Creative Commons licence applying to the text in this book.

Introduction

This chapter introduces the foundation for understanding Medical Circular Living Labs (MCLLs) and their role in enabling circular transformation in healthcare systems. It begins in section 1 by outlining the urgent need for circularity in the medical field, followed by the need for systemic change in healthcare. Next, in section 2 a clear definition and positioning of the MCLL concept is given. Section 3 introduces key circularity frameworks—the R-ladder and the Value Hill—that guide decision-making and intervention design within MCLLs. Finally, section 4 outlines the expected outcomes of MCLLs in terms of environmental impact, innovation, and system-level change.

The Need for Circularity in the Medical Field

Hospitals, and the healthcare sector in general, face a growing sustainability challenge. Hospitals rely heavily on single-use medical consumables, complex supply chains, and strict safety standards that often favour linear "take–make–dispose" models. As a result, the healthcare sector contributes significantly to greenhouse gas emissions, material consumption, and waste generation.

In the Netherlands, the sector is responsible for 7.7% of CO2 emissions, 13% of materials use and 8% of waste produced in the Netherlands (Steenmeijer et al., 2022). Circularity in the Dutch economy is estimated at approximately 24%, while sectors such as healthcare are considered significantly less circular due to high reliance on single-use medical consumables and complex regulatory constraints (Steenmeijer et al., 2022; Hanemaaijer et al., 2023).

At the same time, hospitals must maintain the highest standards of patient safety, hygiene, and regulatory compliance. These conditions make the transition toward circular healthcare particularly complex. New approaches are therefore needed that allow hospitals and their partners to explore circular solutions while managing clinical, organisational, and regulatory constraints.

The development of MCLLs aligns with the growing global movement of integrating circularity (and sustainability in general) into healthcare innovation via Living Labs (LLs). LLs facilitate real-world testing of healthcare circularity through stakeholder-

driven design, testing, and deployment of eco-innovative medical solutions (Puerari et al., 2018). Studies confirm the need for real-life ecosystems for rapid yet inclusive innovation in the healthcare sector. The need for a systemic approach for this complex topic is further explained in the next section.

The Need for Systemic Change

Healthcare systems face a complex sustainability challenge that cannot be addressed through isolated improvements alone. Hospitals depend on resource-intensive infrastructures, extensive supply chains, and large volumes of single-use medical products. While individual innovations, such as more sustainable materials or improved waste management, can contribute to reducing environmental impacts, meaningful progress requires systemic change. This means transforming multiple interconnected elements of the healthcare system simultaneously, including organisational structures, technologies, financial incentives, and regulatory frameworks (Figure 1).

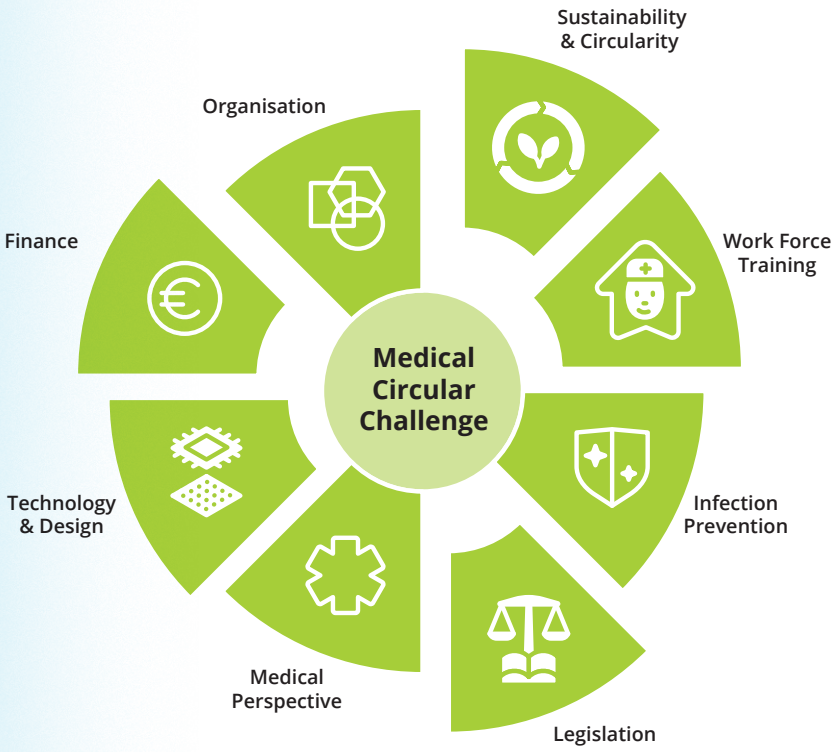


Figure 1 – Mutually Related Aspects of Medical Circular Challenge

Illustration: © Marc Kolle (2026). This illustration is not licensed under the Creative Commons licence applicable to the text of this publication.

Systemic change in healthcare must address several interdependent dimensions. First, there is the organisational dimension, where hospital governance, procurement systems, logistics, and clinical workflows must adapt to support circular practices. Second, the financial and economic dimension plays a critical role: circular solutions must be economically viable, aligned with procurement models, and supported by appropriate reimbursement or investment structures. Third, the transition involves circularity and sustainability, requiring the redesign of products, services, and value chains to reduce waste, extend product lifecycles, and minimise environmental impacts. Systemic transformation also requires progress in the technical and design dimension, where medical devices, consumables, and care processes must be redesigned to enable reuse, repair, remanufacturing, or material recovery.

An important dimension is the specific medical context, where interventions must be tailored to the realities of clinical practice, including specialised procedures, professional routines, and the critical nature of patient care delivery. All changes must further be compatible with the fundamental requirements of patient safety and infection prevention, which remain the highest priority in healthcare environments. Any circular intervention must therefore demonstrate that it maintains or improves safety and hygiene standards. At the same time, innovations must comply with the legislative and ethical dimension, including healthcare regulations, product certification standards, and ethical considerations surrounding environmental responsibility and equitable healthcare delivery. Finally, the impact on the workforce is highly relevant, where circular interventions influence staff roles, require additional training, and must fit within existing time constraints and workload pressures in hospital environments.

Medical Circular Living Labs

Medical Circular Living Labs (MCLLs) can play a crucial role in navigating the interconnected dimensions of systemic change. By bringing together healthcare professionals, researchers, industry partners, educational and academic partners, policymakers, designers, and sustainability experts, MCLLs create collaborative environments where innovations can be developed and tested within real healthcare settings. These Living Labs allow stakeholders to jointly explore how organisational processes, circular design strategies, financial models, regulatory conditions, and clinical safety requirements interact in practice. Through iterative cycles of co-creation, experimentation, evaluation, and learning, MCLLs help identify solutions that work across various dimensions simultaneously. In doing so, they provide a structured pathway for moving from isolated innovations to systemic transformation.

MCLLs offer a real-life research and innovation ecosystem, embedded in a hospital, to collaboratively co-create and test circular interventions that reduce the environmental impact of medical consumables, products, value chains and systems. This means MCLLs are a combination of both **Medical Living Labs** and **Circular Living Labs** (Figure 2). Below is first described in what way Medical Living Labs differ from Living Labs in other sectors. After this, the features of a typical Circular Living Lab are presented, regardless of its sector. Last, this is merged into the topic of this Guidebook – the MCLL.

Medical Living Labs

Medical Living Labs (MLLs) differ fundamentally from Living Labs in other sectors due to the critical role of patient safety, ethics, and regulation in healthcare contexts. While Living Labs in domains such as smart cities, energy, or mobility often focus on usability, efficiency, and active citizen engagement, MLLs must operate within highly regulated clinical environments. Experimentation is therefore inherently more constrained: interventions must be ethically approved, risks carefully managed, and patient safety prioritised above innovation speed. This contrasts with urban

or digital Living Labs, where experimentation can often proceed with fewer formal approvals and greater tolerance for failure (Schuurman et al., 2016; van Geenhuizen & Guldemond, 2018).

A second essential difference lies in the nature of stakeholders and professional cultures involved. Medical Living Labs bring together specialised professionals like clinicians, nurses, infection prevention experts, and hospital managers, whose work is shaped by evidence-based practice, professional accountability, and hierarchical decision structures. In other sectors, Living Labs typically engage citizens, users, designers, and companies with more flexible roles and lower professional risk exposure. Further, healthcare professionals often face limited time, high responsibility, and strong procedural norms, which influence how co-creation and experimentation can be organised (Hakkarainen & Hyysalo, 2013). Consequently, MLLs must carefully adapt co-creation methods to clinical workflows and professional logics, ensuring that participation is meaningful without disrupting healthcare delivery.

Third, MLLs differ in their systemic impact and innovation scope. Whereas Living Labs in other sectors often focus on discrete products, services, or local interventions, MLLs typically address complex socio-technical systems involving clinical practices, supply chains, procurement policies, reimbursement mechanisms, and regulatory frameworks. Innovations in healthcare - especially those related to circularity tend to have cascading effects across the entire value chain, from manufacturers to waste processors. Therefore, MLLs can be seen as learning infrastructures for institutional change (von Wirth et al., 2019; Puerari et al., 2018). This makes MLLs particularly suited for addressing long-term sustainable and circular challenges in healthcare, but it also makes them significantly more complex than Living Labs in other sectors.

Circular Living Labs

Circular Living Labs (CLLs) are collaborative innovation environments where stakeholders jointly develop, test, and implement solutions that support the transition to a circular economy. Like other living labs, they operate in real-life contexts, bringing together stakeholders from industry, government, academia, and civil society to co-create and experiment with new products, services, and systems. What distinguishes CLLs is their explicit focus on closing material loops, reducing waste, extending product lifecycles, and redesigning value chains according to circular economy principles such as reuse, repair, remanufacturing, and recycling. Through iterative experimentation, stakeholder collaboration, and continuous learning, CLLs allow circular innovations to be tested within the complexity of real socio-technical systems, such as cities, industries, or application environments, before they are scaled more widely. In this way, CLLs function as practical transition spaces where new circular practices, business models, and governance approaches can be explored and refined.

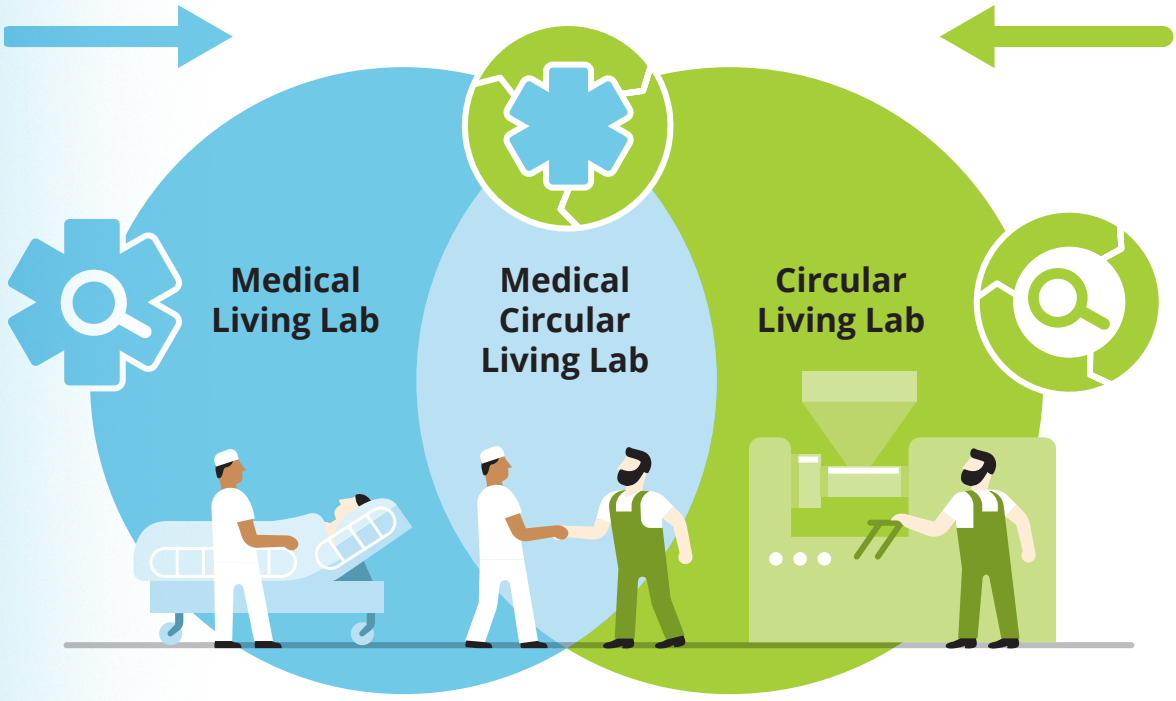


Figure 2: Medical, Circular, and Medical Circular Living Labs

Illustration: © Marc Kolle (2026). This illustration is not licensed under the Creative Commons licence applicable to the text of this publication.

The explicit focus on circularity distinguishes MCLLs from more healthcare-focused MLLs. Circularity directs attention to entire material and value chains, from design and procurement to use, reuse, remanufacturing, and end-of-life management. This means that innovation is framed not only around clinical performance but also around environmental impact, resource efficiency, and long-term system resilience. Circularity therefore expands the scope of the Living Lab beyond the hospital walls, requiring active involvement of manufacturers, suppliers, waste processors, and policymakers as co-innovators.

Also, the circularity focus reshapes how success is defined within MCLLs. Outcomes are evaluated not only by clinical feasibility or user acceptance, but by substantial reductions in material use, waste, and emissions, as well as by the creation of new circular business models and procurement practices. This introduces longer time horizons and iterative learning cycles, as circular interventions often require adjustments to medical routines, long-term purchasing contracts, and regulatory interpretations. As a result, MCLLs should become platforms for multi-level design and transition.

Clearly, an MCLL serves two connected targets – it should support the development of innovations that are feasible according to medical criteria, as well as to circularity criteria. In this Guidebook, attention is therefore given to both these important aspects. In the next section, we will first look into the theme of circularity.

Circularity: R-Ladder and Value Retention in Healthcare

The transition toward circular healthcare requires a clear understanding of how value can be preserved throughout the lifecycle of medical products and materials. Two closely related concepts support this understanding: the **R-ladder** and the **Value Hill**. Together, they provide a structured way to prioritise circular strategies and guide decision-making within Medical Circular Living Labs (MCLLs).

R-Ladder: Hierarchy of Circular Strategies

The R-ladder (Potting et al. 2017) describes a hierarchy of circular strategies (R0–R9), ranging from the most preferred options that avoid resource use altogether to those that recover value at the end of a product's life. This hierarchy helps stakeholders prioritise interventions that maximise value retention and minimise environmental impact.

At the top of the ladder are the most preferred strategies such as Refuse (R0), Rethink (R1), and Reduce (R2), which aim to prevent resource use and minimise environmental impact from the outset.

Further down the ladder are strategies that extend the lifespan of products and components, such as Reuse (R3), Repair (R4), Refurbish (R5), and Remanufacture (R6). These strategies retain much of the original product value by keeping materials and products in use for longer.

At the lower end of the ladder are Repurpose (R7), Recycle (R8), and Recover (R9), which involve transforming or processing materials after their original use phase. While still contributing to circularity, these strategies typically retain less value and often require additional energy or resources.

The Value Hill: Visualising Value Retention

The Value Hill (Achterberg et al., 2016) complements the R-ladder by visualising how value is created, maintained, and lost over the lifecycle of products. It distinguishes three main phases:

- Pre-use phase: where value is created through design, material selection, and production
- Use phase: where value is delivered through the use of products, in our case in clinical practice
- Post-use phase: where value can be retained through circular strategies or lost through disposal

The "hill" illustrates that the highest value is achieved when products are used effectively and maintained over time. Circular strategies aim to keep products as high on the hill as possible by extending their use or returning them to earlier stages in the lifecycle. The closer an intervention remains to the top of the hill, the greater the value retention.

Relevance for Medical Circular Living Labs

In healthcare, applying the R-ladder and Value Hill is particularly challenging due to strict requirements for patient safety, infection prevention, and regulatory compliance. Many current practices rely on single-use products to manage these issues. Recycling (R8) as a circular strategy is the obvious choice, since this does not interfere with the use of the product and its strict requirements. However, MCLLs provide a structured environment in which stakeholders can explore how higher-value circular strategies such as reuse (R3) or repair (R4) can be safely implemented.

Figure 3 illustrates how circular strategies can be applied across the healthcare value chain, linking actors such as manufacturers, hospitals, and waste processors. It highlights how interventions can move products "back up the hill," thereby retaining value and reducing environmental impact. By using the R-ladder and Value Hill as guiding frameworks, MCLLs can prioritise interventions that not only reduce waste, but also fundamentally redesign healthcare systems toward higher-value circular practices.

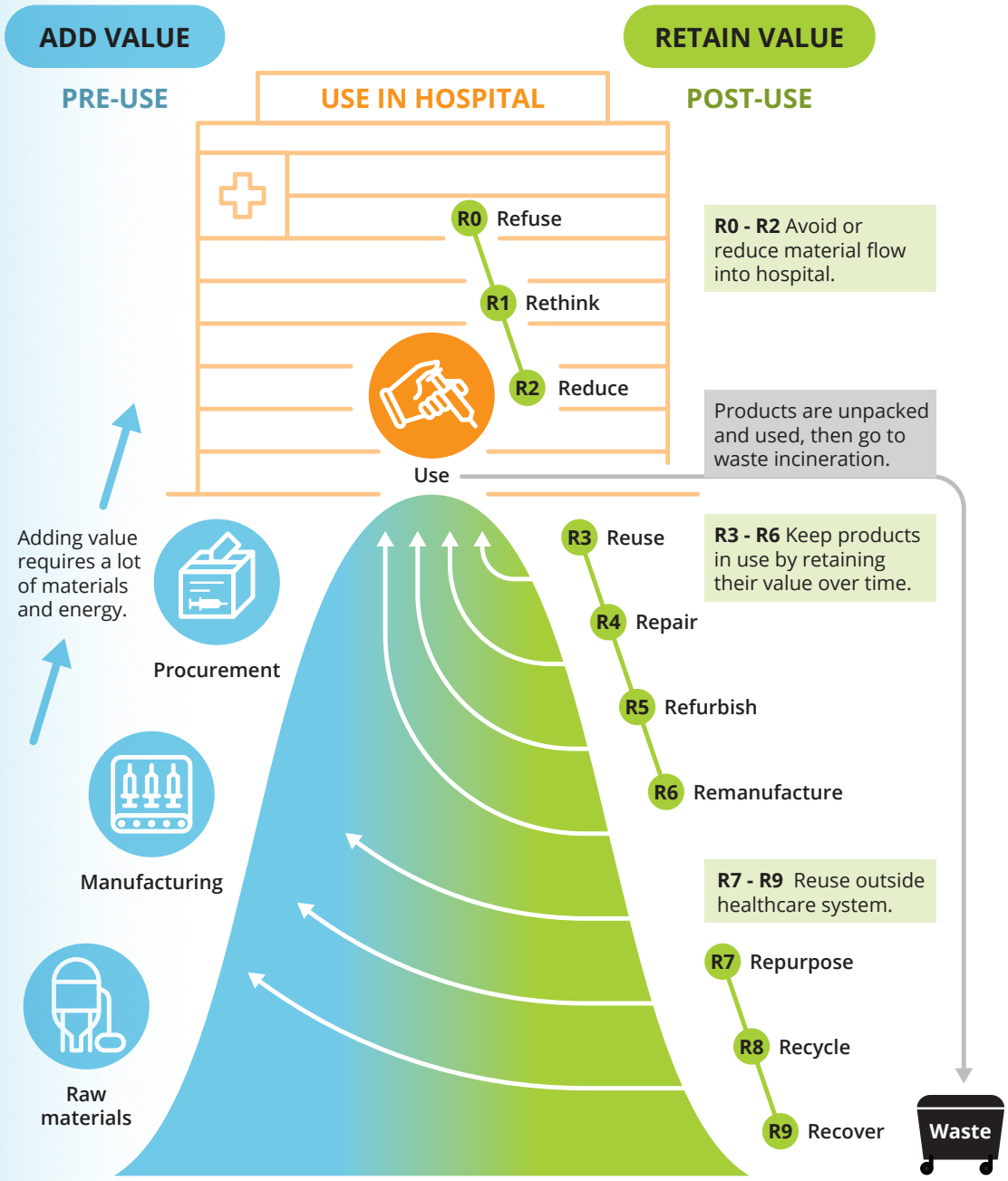


Figure 3: Value Hill and R-Ladder – adding and retaining value

Illustration: © Marc Kolle (2026). This illustration is not licensed under the Creative Commons licence applicable to the text of this publication.

Outcomes of Medical Circular Living Labs

MCLL outcomes can be described and clustered in different ways. However, these are not independent categories. Rather, they form an interrelated set of outcomes that mutually reinforce and enable one another. The development of circular medical consumables generates the basis for environmental impact reduction, while measurable sustainability gains, in turn, strengthen the case for systemic adoption. At the same time, both depend on and contribute to the development of institutional capacity and shared knowledge. In this way, MCLLs can create a coherent ecosystem of outcomes, in which material innovation, environmental performance, system transformation, and learning processes evolve together in a closely related manner.

Circular Medical Consumables, Medical Devices, and Systems

One of the primary outcomes of MCLLs is the development of circular medical consumables, products, value chains, and systems. Through co-creation and real-world testing, hospitals, industry partners, and researchers jointly design and validate alternatives to traditional single-use solutions. The result is a portfolio of evidence-based, co-validated circular interventions, such as reusable medical devices, redesigned consumables, circular procurement models, or improved material recovery processes. Because these interventions are tested in real-life clinical environments and validated with multiple stakeholders, they provide credible pathways for implementation and wider adoption within healthcare systems.

Environmental Impact Reduction

Another key outcome of MCLLs is measurable improvement in the environmental performance of healthcare operations. Circular interventions developed and tested within the Living Lab aim to reduce the environmental footprint of medical treatments and hospital processes. This can include reductions in CO_2 emissions, waste generation, and the use of virgin materials, achieved through strategies such as reuse, product redesign, material substitution, and improved waste management. By collecting environmental performance data during the testing and validation phases, MCLLs generate robust evidence that supports the integration of circular solutions into hospital sustainability strategies.

Sustainable and Resilient Health Systems

Beyond individual interventions, MCLLs contribute to the development of more sustainable and resilient healthcare systems. Successful Living Lab initiatives often lead to the institutionalisation of Living Lab practices within hospitals, allowing experimentation and circular innovation to continue beyond the duration of a single project. In addition, the knowledge and methodologies developed within MCLLs can be translated into replicable tools, methods, and frameworks that can support other hospitals in establishing their own circular innovation environments. In this way, MCLLs help build the institutional and methodological foundations needed for systemic change across the healthcare sector.

Knowledge and Capacity Building

MCLLs also generate important outcomes in terms of knowledge creation and human capacity development. By bringing together partners from academia, industry, and healthcare practice, Living Labs strengthen collaboration across sectors and disciplines. This collaborative environment fosters new insights into circular healthcare systems, innovation processes, and sustainable medical technologies. At the same time, MCLLs contribute to the education and training of a new generation of circular healthcare innovators, including students, researchers, clinicians, and industry professionals who gain hands-on experience in co-creation, experimentation, and circular design.



Photograph © Jan Geerling, 2016. Source: Wikimedia Commons. Licensed under CC BY-SA 4.0



Photograph © Sneeuwvlakte, 2025. Source: Wikimedia Commons. Licensed under CC BY-SA 4.0

Case Example
ESCH-R Project

This publication is based on experiences in ESCH-R. The acronym ESCH-R stands for Evidence-based Strategies to create Circular Hospitals: Applying the 10-Rs framework to healthcare (Huijben et al., 2025). In ESCH-R, two Medical Circular Living Labs (MCLL) are developed. One at Erasmus University Medical Center in Rotterdam, and one at University Medical Center Utrecht, the Netherlands. These MCLLs serve as real-world innovation ecosystems to co-develop, test, and validate circular interventions for medical consumables. This way, MCLLs serve both as testing grounds for circular healthcare practices as well as learning environments for multi-stakeholder collaboration.

Each MCLL consists of one central Co-Creation Lab and three embedded Clinical Living Labs. At Erasmus University Medical Center, the Clinical Living Labs are linked to the departments of Obstetrics, the Heart Catheterisation Lab, and the Intensive Care Unit. At University Medical Center Utrecht, the Clinical Living Labs are embedded within the departments of Eye Surgery, Robotic Surgery at Urology, and Nephrology.

Within these settings, stakeholders from healthcare, academia, and industry collaboratively identify environmental hotspots, select high-impact consumables, products, value chains, and systems, and co-create a range of circular interventions using design thinking and circular design methods. These interventions are iteratively prototyped and validated both in clinical practice and across the value chain, while educational and research activities foster joint innovation. The goal of this guidebook is to support the replication of similar initiatives in other hospitals, supporting the systemic reductions in waste, emissions, and virgin material use in healthcare.



Chapter 3

When to Use Medical Circular Living Labs



Photograph © Jan-Carel Diehl, 2026. All rights reserved. Reproduced with permission.
This image is excluded from the Creative Commons licence applying to the text in this book.

Different Approaches for Innovation in Healthcare

Innovation in healthcare can take many forms. Next to Living Labs (and in this specific case, Medical Circular Living Labs) also Conventional R&D, Simulation Labs, Pilot Projects, and Co-Creation Labs are often well suited to find interventions to problems and requirements for sustainability and circularity. Of course, in many situations a mix of these innovation approaches is used, depending on the requirements and context of the problem and the interventions developed. At the same time, it is still relevant to understand the specific benefits of each of these approaches.

Medical Circular Living Labs (MCLLs) are specifically used for "wicked problems" which consist of clinical, regulatory and behavioural elements. Here, systemic change is needed without knowing beforehand what parts and relations of the system must be changed in what way. MCLLs are then used as a real-world setting where diverse stakeholders (e.g., clinicians, patients, industry, policymakers, academia) co-create, test, and validate innovations over time. MCLLs are most appropriate when innovation must be adapted to complex systems with behavioural, regulatory, and organisational dimensions, such as circular procurement, circular products and systems, or reconfiguration of care pathways. MCLLs enable iterative, inclusive development but require significant coordination, governance, and time.

Conventional R&D (e.g., university labs or industrial research units) is effective for early-stage, technical discovery, and focus on technological proof-of-concept. Real-world feedback or user input is typically done in later stages. Use Conventional R&D for early-stage discovery, technical proof-of-concepts. This approach is best for lab-based discovery before clinical or systemic integration.

Simulation Labs replicate clinical environments for training and controlled testing, and are ideal for evaluating safety, technical usability, and procedural accuracy. Use a Simulation Lab for risk-free evaluation of usability, workflow, safety. This approach is best for early usability or procedural evaluations without patient risk, providing a safe controlled place for testing of procedures, tools, or workflows, but still with all stakeholders.

Pilot Projects offer time-limited testing and validation of innovations in real settings, typically without the ongoing co-creation and stakeholder involvement that are typical of Living Labs. They are useful for measuring feasibility and short-term impact but may overlook systemic issues or long-term integration. Use a Pilot Project for limited-scope real-world test for feasibility. This approach is best for short-term, real-world tests focused on feasibility or outcomes.

Co-Creation Labs are mainly focused on the conceptual design process, supporting the active collaboration of various stakeholders during the process, but without the actual testing of the developed solutions in a real-life environment. Use a Co-Creation Lab for participatory co-creation with different stakeholders. This approach is best for active participation with various stakeholders, without actually implementing the developed solutions in a real-life environment.

Selecting an Appropriate Innovation Approach

A simple decision process can help to determine whether an MCLL is the best approach to use in the case of a specific project, or that another innovation approach may be more feasible. Below four questions can be used to determine which innovation format fits a specific healthcare challenge. The decision process is visualized in Figure 4.

- Is the problem complex and systemic, meaning that it involves multiple dimensions (clinical, behavioural, regulatory, organisational) and requires more than just a technical fix?
- Does the innovation require active co-creation across various stakeholders, so are multiple stakeholders (e.g., clinicians, procurement, medtech, sustainability, patients, regulators) needed to co-create and adapt the solution?
- Is the innovation primarily early-stage technical or scientific research? – It is about testing materials, technologies, or functions without needing user involvement or real-world integration.
- Must the innovation be tested in a real-world clinical environment? Is real-world clinical integration essential to assess the viability or acceptance of the solution? Is the solution matured enough to be tried in a live healthcare setting?

Use an MCLL if the problem is complex and systemic, if there is a need for active co-creation across various stakeholders, and if the innovation should be tested in a real-world environment. However, if it is about early-stage technical or scientific research, a conventional R&D lab may be more suitable. If no active co-creation is needed, perhaps a simulation lab or pilot project may be better options. And if the focus is mainly on co-creation, but no active testing in a real-world environment is needed yet, then a Co-Creation Lab may be the best option.

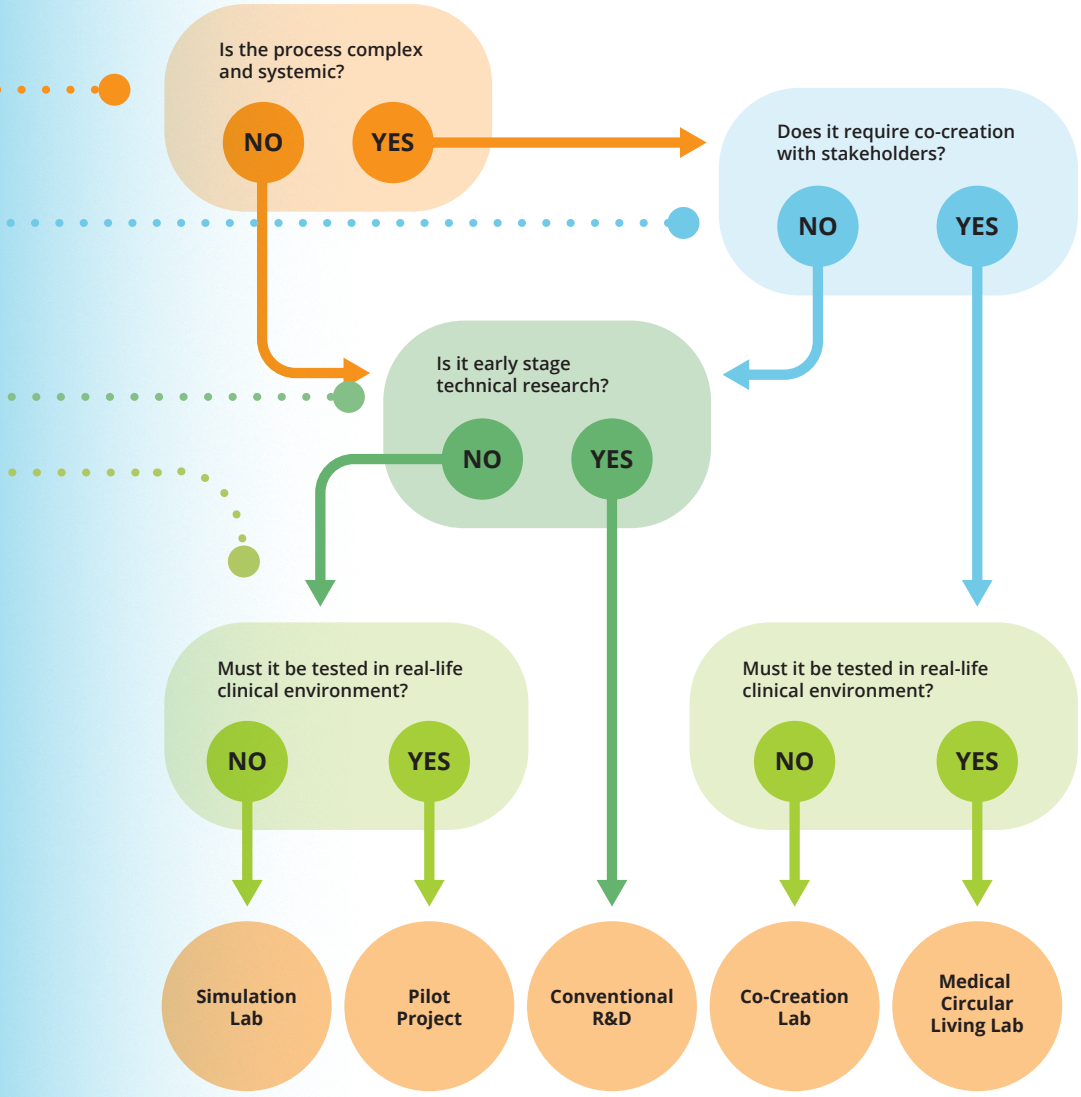


Figure 4: Selecting an Appropriate Innovation Approach

Illustration: © Marc Kolle (2026). This illustration is not licensed under the Creative Commons licence applicable to the text of this publication.

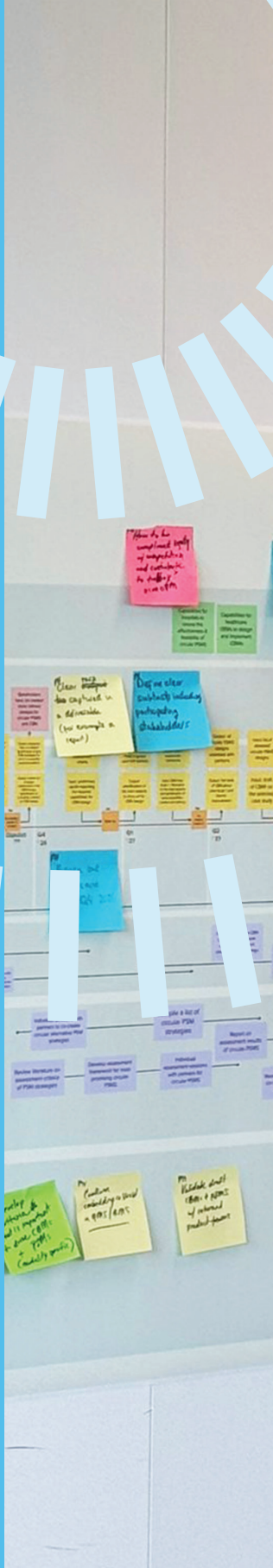


Photograph © Fiene Kuiper, 2026. All rights reserved. Reproduced with permission.
This image is excluded from the Creative Commons licence applying to the text in this book.

Case Example
Sustainable Pulse Oximeter

This graduation project by Kuiper (2025) conducted at Delft University of Technology in collaboration with Erasmus University Medical Center, Philips Medical, and the ESCH-R consortium, explored how pulse oximeter systems in hospitals can be redesigned to reduce environmental impact while maintaining clinical reliability and usability. Pulse oximeters continuously measure blood oxygen saturation in patients. Hospitals rely heavily on disposable sensors. This despite reusable alternatives being available, which have a substantially lower environmental impact. Using a systems-oriented and circular design approach, the project investigated both the product itself and the broader hospital system. Several barriers were identified preventing hospitals from adopting reusable pulse oximeters at scale, including concerns about hygiene and cleaning compliance, sensor loss during patient transfers, cable breakage, dirt accumulation, alarm fatigue, discomfort for patients, and limitations in current hospital workflows.

The project resulted in the design of a hybrid pulse oximeter, based on a reusable sensor base combined with a replaceable single-use adhesive patch. The concept aimed to combine the sustainability advantages of reuse with the hygiene, comfort, and usability benefits of disposables. The design incorporated multiple circular strategies including reuse, repairability, durability, material recovery, and traceability. This case demonstrates the importance of combining product design, systems thinking, stakeholder collaboration, lifecycle analysis, and circular business models to enable meaningful transition toward circular healthcare systems.



Chapter 4
Foundational Principles



Photograph © Maaike van Zuilen, 2026. All rights reserved. Reproduced with permission.
This image is excluded from the Creative Commons licence applying to the text in this book.

Introduction

Medical Circular Living Labs are grounded in eight foundational principles that together define how they operate within the complexity of healthcare systems. An MCLL is foremost focused on (A) complex circular challenges in hospitals, embedded in hospital environments and connecting relevant partners around shared sustainability goals. It functions through (B) stakeholder-centred co-creation, ensuring that healthcare staff, industry, researchers, and policymakers jointly shape circular interventions. The work is guided by (C) systems thinking and circular design, recognizing that medical products, value chains, and organisational routines are interdependent and must be redesigned holistically, with a focus on circularity.

At the same time, MCLLs are structured around (D) continuous learning, fostering iterative reflection, feedback loops, and institutional learning across experiments. They are always embedded in a (E) real-world setting, meaning that innovation takes place within clinical environments where safety, regulation, and workflow constraints are reality. Finally, MCLLs embrace (F) open-ended outcomes, acknowledging uncertainty and allowing solutions to evolve through experimentation rather than being predefined from the outset. This is done through multiple loops of an (G) iterative innovation process, which aims to (H) connect hospital departments. These foundational principles are described in detail below.

Principle A. Focus on Circular Challenges in Hospitals



Medical Circular Living Labs (MCLLs) are specifically designed to address complex circular challenges that arise within hospital environments. These challenges are inherently systemic in nature, involving the interaction of clinical practices, material flows, procurement systems, regulatory requirements, and stakeholder behaviours. Rather than focusing on isolated improvements—such as single-product substitutions or incremental waste reductions—MCLLs target interconnected problems where multiple dimensions must be addressed simultaneously.

In practice, this means that circular challenges are approached at the level of systems rather than individual components. Systems interdependencies make circular innovation in healthcare fundamentally different from linear optimisation problems.

By focusing on such complex challenges, MCLLs create space for integrated solutions that combine environmental impact reduction with clinical safety, operational feasibility, and economic viability. This focus also justifies the need for a Living Lab approach: only through real-world experimentation, multi-stakeholder collaboration, and iterative learning can these systemic challenges be effectively addressed.



Principle B. Co-Creation with Stakeholders

MCLLs practice co-creation through the active and continuous involvement of relevant stakeholders, including clinicians, hospital management, industry partners, researchers, and students. Their diverse perspectives and expertise are essential for developing interventions that are innovative, feasible, safe, and scalable in real-world healthcare settings.

Co-creation is not limited to ideation as it spans the entire innovation process. This ensures that solutions are grounded in practice and responsive to organisational, economic, and environmental requirements. Stakeholders collaboratively explore and map existing systems, including clinical workflows, material and resource flows, stakeholder roles, regulatory constraints, and ecological impacts. By integrating multiple perspectives, a shared understanding is developed of inefficiencies, risks, and opportunities for circularity.

Building on this shared understanding, stakeholders jointly design and refine potential interventions through iterative ideation, prototyping, and feedback. Clinical needs, circularity goals, economic considerations, and technical feasibility are considered throughout the process. This increases the relevance, feasibility, and acceptance of proposed solutions among those who will implement or be affected by them.

Interventions are subsequently tested in real-life healthcare settings with the continued involvement of end-users and other stakeholders, with continuous feedback loops supporting iterative improvement.

Principle C. Systems & Circularity Thinking



MCLLs apply a combination of design thinking, systems thinking, and circular design approaches to address the complexity of healthcare systems and enable meaningful circular innovation. Systems thinking supports understanding how clinical practices, supply chains, regulations, user behaviours, and institutional structures interact within the broader healthcare ecosystem. Circular design complements this by focusing on strategies that minimise resource use, extend product lifecycles, and reduce environmental impact across the entire value chain. Together, this supports the development of interventions that move beyond incremental improvements toward systemic transformation.

To operationalise these perspectives, MCLLs employ a range of methods and tools. Visual thinking methods such as system maps, stakeholder maps, journey maps, and material flow diagrams, can help to make complex systems tangible and understandable. These approaches support shared understanding among stakeholders, reveal hidden interdependencies, and identify inefficiencies and opportunities for circular interventions.

Ideas and interventions are developed iteratively through prototyping and experimentation in real-world or representative healthcare settings. This enables stakeholders to test assumptions, explore feasibility, and identify unintended consequences early in the process. Within healthcare contexts, experimentation includes not only technical prototypes, but also redesigned workflows, service models, and circular strategies.

MCLLs can use scenario development and strategic roadmapping to explore possible future pathways for circular healthcare systems. These approaches take into account uncertainties such as technological developments, policy changes, and evolving healthcare demands. Strategic roadmaps can help translate future scenarios into actionable steps and align short-term interventions with long-term transformation goals, ensuring that individual projects contribute to broader systemic change rather than remaining isolated initiatives.

In addition, MCLLs apply circular design frameworks to guide the development and evaluation of interventions. In particular, the 10-Rs framework, as described in Chapter 2, provides a structured hierarchy of circular strategies. Emphasis is placed on higher-order and preventative strategies because these offer the greatest potential for systemic impact. This encourages stakeholders to fundamentally challenge and redesign existing practices instead of relying primarily on lower-value strategies such as recycling.

Through the combined use of these approaches, MCLLs can help stakeholders to better understand complexity, develop more effective interventions, and contribute to the transition toward a circular and sustainable healthcare system.



Principle D. Continuous Learning

Continuous learning in MCLLs ensures that circular innovation can evolve through structured cycles of reflection, experimentation, and institutional embedding rather than through linear project execution. MCLLs rely on iterative and cyclical learning processes. Experiential learning can be described as a continuous cycle of experience, reflection, abstraction and action (Van der Wee et al., 2024). Iterative feedback plays a central role, supported through recurring feedback meetings and learning-by-doing processes that continuously connect action and reflection (Von Wirth et al., 2019).

Experimentation within MCLLs functions as a collective learning process in real-world settings, where diverse stakeholders collaboratively reduce uncertainty surrounding sociotechnical innovations while generating practical knowledge through iterative learning cycles. This allows interventions to be continuously refined based on emerging insights and contextual feedback. Continuous learning also takes place across experiments and projects through meta-learning approaches. Networked living labs can facilitate the exchange, comparison, and redistribution of lessons learned between different experiments and contexts (Scholl et al., 2022). This

includes systematic documentation practices, dedicated reflection activities, and recurring learning sessions in which completed experiments are evaluated and compared.

To ensure long-term impact, learning processes need to become institutionally embedded. Knowledge generated through experiments can for instance be integrated into higher education programmes and organisational practices. In addition, structured monitoring and evaluation frameworks can support continuous reflection on impacts, partnership dynamics, participation processes, and organisational development (Verhoef et al., 2020). Continuous learning faces several challenges. Living Lab initiatives may be constrained by short project timelines and insufficient long-term strategies (Tercanli et al., 2022). Institutional norms that prioritise efficiency and productivity may also limit opportunities for experimentation and reflection (Van der Wee et al., 2024). Furthermore, effective collaborative learning requires sustained investment in relationships and interaction capacities.

Principle E. Real-World Setting

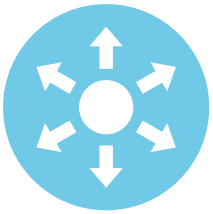


MCLLs take place in a real hospital environment. This means that circular innovations must function under the real pressures of clinical work. Only in actual hospitals and care environments can complexity, workflow interruptions, hygiene needs and unexpected situations be observed realistically. Testing in practice allows clinicians, patients and support staff to interact directly with interventions, generating feedback, ownership and insight into habits, usability and acceptance. This support adoption of innovations, as this strongly depends on people, not just on technology.

The real-world approach includes hospitals providing real waste streams, sterilization flows, packaging volumes, routing patterns and supply chains, information that cannot be simulated accurately outside practice. This is essential as circularity is strongly material- and system-based. Innovation within medical settings requires

strict hygiene, safety and ethical standards. Real environments allow for controlled testing to ensure innovations meet clinical requirements and integrate safely into patient care.

Real-world experimentation provides measurable outcomes: waste reduction, lifecycle performance, cost effects, carbon savings and satisfaction levels. This evidence is essential for decision-making, investment and upscaling. Circular transitions also involve procurement, regulation, business models and partnerships. In-situ testing enables collaboration across stakeholders, supports new value chains and accelerates the shift from linear to circular healthcare systems.



Principle F. Open-Ended Outcomes

An important principle for MCCLs is their openness to emergent outcomes. Unlike traditional healthcare innovation processes, which often aim for pre-defined deliverables and tightly controlled pathways, MCLLs embrace a more adaptive and exploratory approach. The goal is not to know from the outset exactly what the final outcome will be, but rather to establish a flexible framework that allows innovation to evolve in response to new insights, stakeholder feedback, and contextual shifts within the hospital environment. This “fuzzy front end” of innovation is essential in addressing complex, multi-layered sustainability challenges, where the underlying problems - the “problem behind the problem” – often only become visible through experimentation and dialogue.

In such an open system, uncertainty is not a weakness but a design principle. Circular healthcare interventions often interact with diverse domains - logistics, procurement, clinical routines, and regulatory structures - that cannot be fully mapped in advance. By maintaining openness in both goals and methods, MCLLs can continuously adjust their course as new evidence and stakeholder needs emerge. Hospitals, though traditionally hierarchical and procedural, benefit from this experimental mindset as it enables them to test systemic changes within controlled, real-world settings without committing prematurely to a single technological or operational solution.

Principle G. Iterative Innovation Process



Rather than following a linear pathway from problem definition to solution implementation, MCLLs operate through continuous cycles of learning and adaptation. Innovation unfolds through iterative loops of co-creation, design, testing, evaluation, and redesign. This iterative approach is particularly suited to healthcare systems, which are widely understood as complex adaptive systems where interventions often produce unpredictable and context-dependent outcomes.

Each iteration serves several functions. First, it deepens understanding of the system by uncovering latent needs, constraints, and interdependencies that may not have been visible during initial analysis. Second, it enables the refinement of hypotheses and intervention strategies, so that solutions are better aligned with clinical workflows, user needs, and organisational realities. Third, it allows for early identification of unintended consequences—an essential feature when working in safety-critical environments such as healthcare (Turk et al., 2025).

The cyclical nature of this process fosters a structured form of learning-by-doing. Data collected during testing can feed directly into next design iterations. Thus, evidence and practice continuously inform each other. Moreover, iteration supports alignment across stakeholders. By repeatedly engaging clinicians, researchers, managers, and industry partners through the cycles, MCLLs ensure that different perspectives are integrated over time, reducing resistance to change and increasing the likelihood of successful implementation.

Iteration also enables flexibility. As external conditions change—such as new regulations, technological developments, or shifting sustainability targets—MCLLs can adapt ongoing projects. This makes the innovation process resilient and responsive.



Principle H. Connecting Hospital Departments

Healthcare systems in hospitals are organised in highly specialised units, sometimes leading to siloed ways of working, for instance between clinical departments, between professional groups (such as doctors, nurses, and technicians), and between functions like procurement, logistics, and sustainability. While efficient within domains, these silos create barriers to circular innovation, which typically spans multiple organisational, professional, and value chain boundaries.

Medical Circular Living Labs (MCLLs) address this challenge by bringing diverse stakeholders and professional groups like doctors and nurses together in a shared process of co-creation, testing, and implementation. By aligning perspectives, fostering collaboration, and creating a common understanding across disciplines, MCLLs enable integrated solutions that would not emerge within isolated structures.

Breaking through silos requires active coordination, shared goals, and continuous engagement across stakeholders. As a foundational principle, it ensures that circular interventions are not only technically viable, but also organisationally embedded and scalable within the healthcare system.

Case Example
Medified, Finland

The Medified case (Hannula, 2021) illustrates how a Medical Living Lab can support the iterative co-creation and implementation of digital healthcare innovation within a real clinical environment. A digital mental healthcare service was developed by the startup Medified Solutions Oy in collaboration with a Finnish public healthcare organisation functioning as the Living Lab environment. Healthcare professionals integrated the new service into daily clinical routines while simultaneously contributing feedback, identifying practical barriers, and participating in iterative refinement of the solution.

The Living Lab approach enabled continuous testing, evaluation, and refinement within an operational healthcare setting, ensuring that the innovation evolved in close alignment with existing workflows, organisational structures, and practical needs of healthcare professionals. Through iterative cycles of interviews, feedback sessions, prototyping, and real-world use, the intervention evolved from an early-stage prototype into an integrated and implementation-ready solution. The co-creative setup facilitated mutual learning between the startup and the healthcare organisation. The company gained insight into clinical realities and organisational constraints, while healthcare professionals assessed feasibility, usability, and long-term potential of the new service.

The case demonstrates how Medical Living Labs can function as intermediary innovation environments bridging the gap between technological innovation and healthcare practice by supporting iterative adaptation, stakeholder alignment, and learning in real clinical contexts. At the same time, the case identifies several challenges like the integration of new services into established clinical routines, coordination across multiple stakeholders, limited time availability of healthcare professionals, and the influence of regulatory and organisational procedures on innovation speed and implementation.

Foundational Principles of Medical Circular Living Labs



Principle A.
Focus on Circular Challenges in Hospitals

Addressing interconnected environmental, clinical, and organisational challenges.



Principle B.
Co-Creation with Stakeholders

Combining diverse perspectives to create feasible and supported solutions.



Principle C.
Systems Thinking and Circular Design

Identifying connections, dependencies, and opportunities for system-wide improvement.



Principle D.
Continuous Learning

Building knowledge through reflection, experimentation, and shared experience.

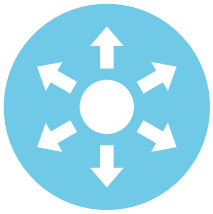
Principle E.
Real-World Setting

Testing innovations and generating insights under actual clinical and organisational conditions.



Principle F.
Open-Ended Outcomes

Allowing solutions to emerge through exploration and learning, without predetermining the final solution.



Principle G.
Iterative Innovation Process

Improving interventions through repeated cycles of testing, evaluation, and improvement.



Principle H.
Connecting Hospital Departments

Bridging disciplines, aligning expertise and activities across organisational boundaries to enable integrated innovation.





Chapter 5
Multi-Level Framework



Photograph © Erasmus MC Rotterdam, 2026. All rights reserved. Reproduced with permission.
This image is excluded from the Creative Commons licence applying to the text in this book.

Introduction

In this guidebook, we analyse Medical Circular Living Labs (MCLLs) as an approach that connects different levels of system transformation: The level of the (inter) national **healthcare and hospital ecosystem** (top), the **department-level innovation system** (middle), and the level of **assessments and experiments in real-life clinical settings** (bottom). These three levels help clarify where innovations are targeted, which stakeholders are involved, how governance and decision-making responsibilities are distributed, and how innovation processes unfold across different contexts and aggregation levels (Figure 5).

One of the strengths of the MCLL approach lies in its ability to work simultaneously across these different systemic levels. An MCLL may begin with testing a circular innovation at the level of real-life experiments, then adapt sterilization protocols at the department level, and finally co-develop new procurement criteria with suppliers at the level of the hospital and healthcare ecosystem. The ambition is that MCLLs support horizontal collaboration (across departments and sectors) as well as vertical integration (from operation to policy), thus supporting systemic circular transformation in healthcare.

Healthcare Ecosystem

The first level of the multilevel framework comprises both the broader (inter)national healthcare ecosystem and the hospital ecosystem (Figure 6). Together, they form the structural, financial, organisational, and policy context that enables or constrains circular innovation in healthcare. The healthcare ecosystem is representing the broader structural, financial, and policy environment that enables or constrains long-term circular transitions in healthcare. This level provides the governance structures that shape circular innovation through legislation, funding mechanisms, procurement frameworks, sustainability policies, and sector-wide agreements. For instance, health related Green Deal initiatives may reflect national or European ambitions related to improved circularity in hospitals.

The healthcare innovation ecosystem is a highly networked, publicly regulated system, combining strong government steering with active private-sector innovation. At the heart of the ecosystem are the healthcare providers like hospitals, mental healthcare institutions, elderly care organisations, and primary care givers.

Other relevant stakeholders include government and public agencies like the Ministry of Health, Welfare and Sport, funding agency ZonMw - The Netherlands Organisation for Health Research and Development - and local government representatives like municipalities and administrative organisations. Stakeholders also include knowledge and research institutions like universities and university medical centres (UMCs), research institutes such as TNO – Netherlands Organisation for Applied Scientific Research - and Universities of Applied Sciences focusing on practice-based innovation.

Then there are industrial stakeholders, varying from multinational medtech and pharmaceutical companies to national health and medical device companies, to small startups focused on specific innovation initiatives. This category also includes waste collection and processing companies responsible for medical and hazardous healthcare waste under strict regulatory conditions. Important stakeholders with regards to financing and payment include health insurers, which play a distinct role by purchasing care and strongly influencing the adoption of innovation through reimbursement decisions for specific costs and medical treatments.

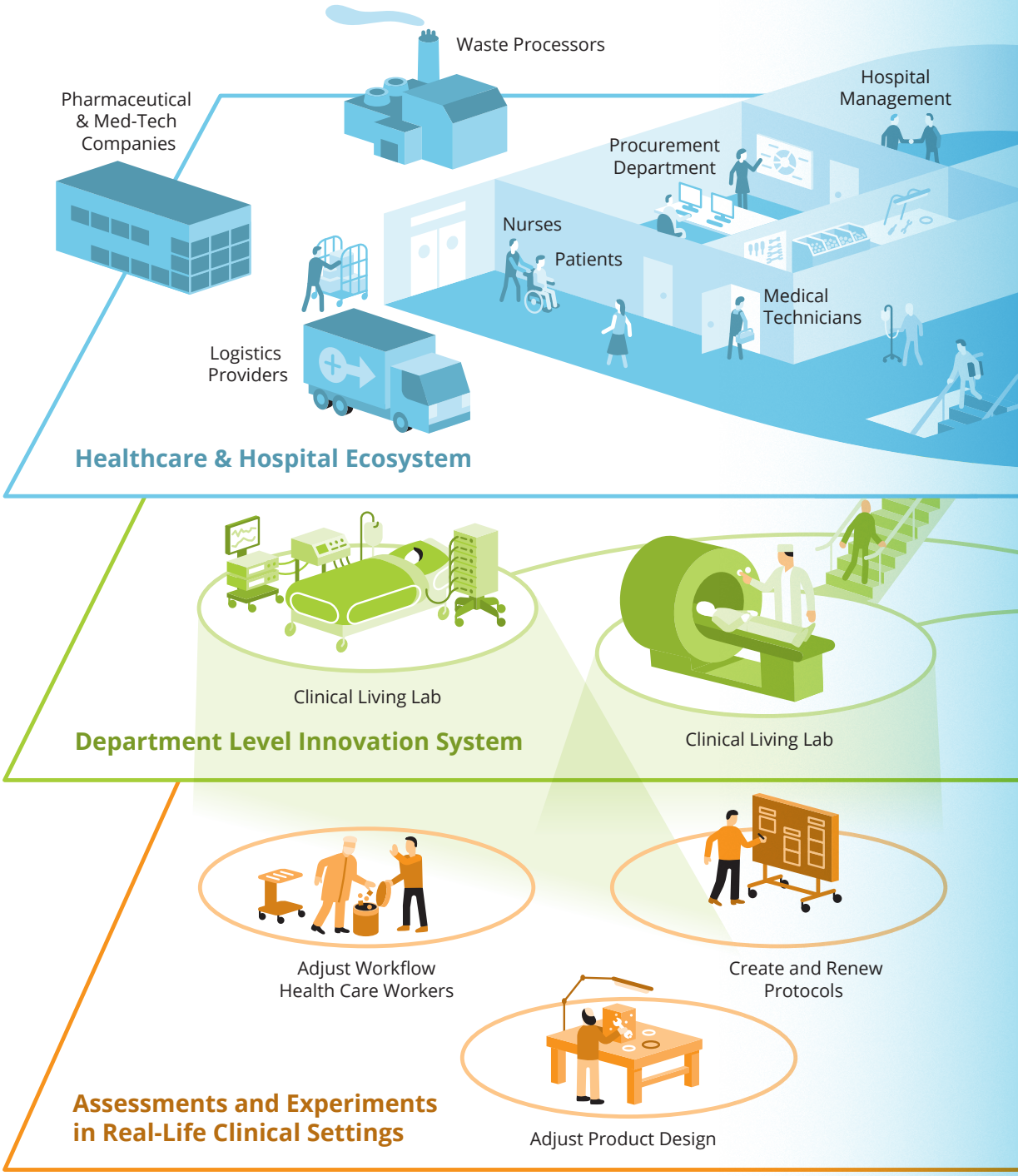
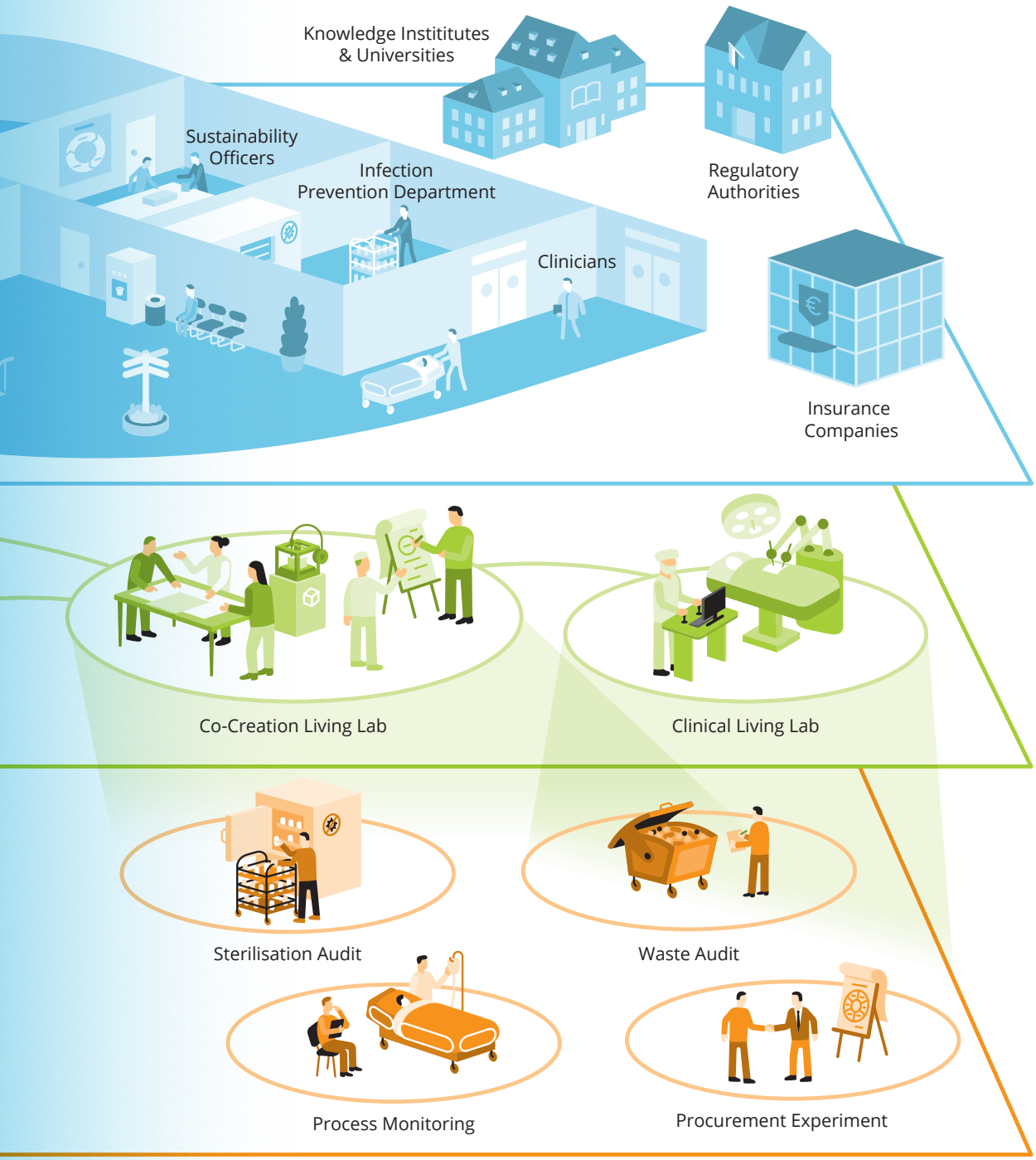


Figure 5: Medical Circular Living Labs- Multilevel Framework

Illustration: © Marc Kolle (2026). This illustration is not licensed under the Creative Commons licence applicable to the text of this publication.


Knowledge Instititutes
& Universities
Regulatory
Authorities
Sustainability
Officers
Infection
Prevention Department
Clinicians
Insurance
Companies
Co-Creation Living Lab
Clinical Living Lab
Sterilisation Audit
Waste Audit
Process Monitoring
Procurement Experiment

Hospital Ecosystem

As part of the first level, the hospital innovation system represents the internal organisation in which healthcare delivery, material use, waste management, and all innovation processes take place. The hospital innovation system is a complex and highly regulated organisation, characterized by strong clinical autonomy combined with hierarchical management and functional specialization. At the heart of this system are the clinical departments, represented by medical specialties, surgical units, diagnostic departments, and nursing wards, where patient care is delivered and where most material consumption and waste generation occurs.

Other stakeholders include hospital governance and management, which define strategic priorities, allocate financial resources, and establish organisational policies. Other departments play a crucial role in shaping material flows and waste practices, including procurement and supply chain management, infection prevention, facilities and technical services, logistics, finance and control, legal affairs, quality and safety, and information and communication technology. Waste and materials management concerns a distinct and highly regulated component of the hospital system, including functions responsible for medical waste, hazardous materials, infection prevention and control, sterilization and reprocessing, and environmental services. All stakeholders operate under strict legal, safety, and hygiene requirements. Each of these strongly influences which circular strategies are feasible, such as reuse, recycling, segregation of waste streams, and substitution of single-use plastics.

Knowledge and innovation-oriented stakeholders within the hospital system include research and education departments, sustainability or circularity teams, innovation offices, and clinical champions within departments such as green teams. These can support experimentation, collaboration with external partners, and the translation of circular ambitions into tangible innovations.

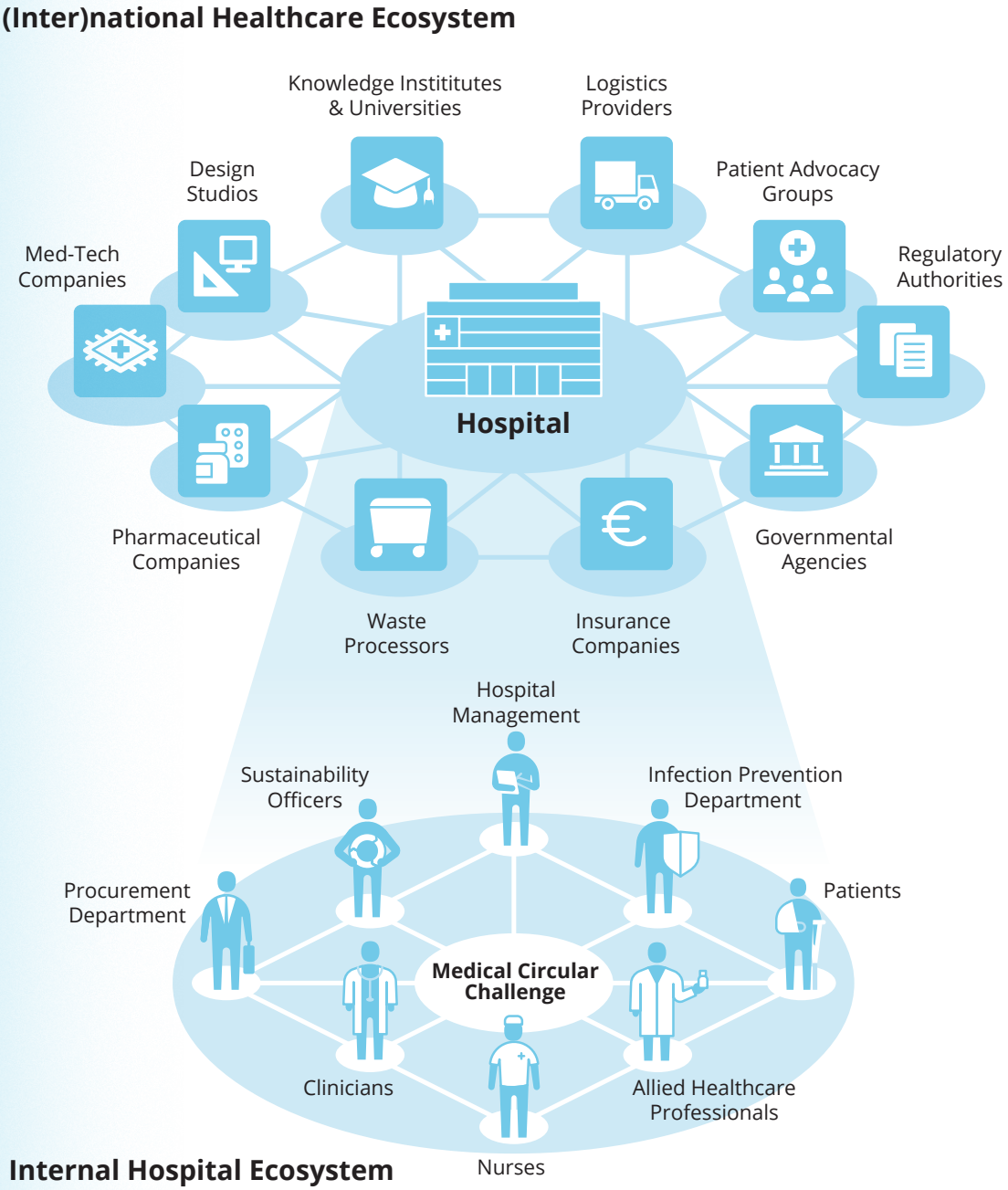


Figure 6: Healthcare and Hospital Ecosystem

Illustration: © Marc Kolle (2026). This illustration is not licensed under the Creative Commons licence applicable to the text of this publication.

Department-Level Innovation System

The middle level of the multilevel framework is the department level: the local operational system where daily clinical practices, material use, and waste generation occur. Here, innovation meets routines, professional decisions, and practical constraints within a specific clinical context. Each department represents a highly regulated system shaped by clinical protocols, safety standards, and professional norms. At its core are healthcare professionals, including physicians, nurses, and support staff, who are responsible for patient care and make daily decisions regarding the use of medical devices, consumables, and disposable materials. These decisions largely determine patterns of material consumption and waste generation. Other stakeholders include departmental leadership, which organizes workflows, allocates staff capacity, sets priorities, and balances clinical demands, hospital policies, and resource constraints.

Departments are closely connected to supporting functions such as procurement, logistics, sterilization, waste management, infection prevention and control, and facilities services, which determine material availability, material use, and the way that waste is collected, segregated and processed. Knowledge and innovation-oriented stakeholders include clinical champions and staff involved in research, education, and pilot projects. They play a key role in identifying opportunities to reduce waste and plastic use, testing alternative materials and practices, and translating circular ambitions into changes compatible with clinical quality, safety, and regulatory requirements.

Interventions in Real-Life Clinical Settings

The third, most concrete level of the multilevel framework is about small-scale, tangible interventions, situated within real-life hospital environments. These interventions are embedded in everyday clinical practice and focus on testing

circular interventions in the context where material use, waste generation, and care delivery directly intersect. Experiments typically take place within specific departments, wards, or care pathways. Examples include projects aimed at reducing single-use plastics, improving waste segregation, introducing reusable alternatives, or redesigning material flows around specific procedures. The real-life setting ensures that experiments account for clinical workflows, safety protocols, hygiene requirements, and regulatory constraints.

Concrete experiments allow for learning-by-doing, ensuring that practical insights emerge through use, adaptation, and iteration. Feedback from healthcare professionals and supporting services such as procurement, sterilization, and waste management is essential to assess feasibility, compliance, and impact of specific innovations. At the same time, data on material use, waste streams, and operational implications can be collected to support evaluation and decision-making.

Medical Circular Living Labs as Linking Mechanism

Medical Circular Living Labs (MCLLs) connect the various levels of the healthcare system (Figure 8). They are primarily situated at the department level or take place as a combination of more active departments. MCLLs do not encompass all activities within a department, nor are they limited to individual experiments. Instead, MCLLs provide an organised context in which concrete innovations can be designed, tested, and reflected upon in relation to hospital-wide strategies and broader system-level ambitions for circular healthcare. By bringing together stakeholders from departments, hospital support functions, and external partners, MCLLs act as a linking pin between the hospital innovation ecosystem and real-life experimentation. They support coordination, decision-making, and learning across levels, helping to align local innovations with organisational strategies and broader healthcare sustainability ambitions. MCLLs enable learning across levels by translating circular ambitions into practical experiments. Within the overall approach of MCLLs, a distinction can be made between two different types of labs: Co-Creation Labs and Clinical Living Labs (Figure 7).

Co-Creation Labs

Co-Creation Labs focus on the early phases of innovation, where new ideas aimed at reducing material use and waste are explored and developed. Co-Creation Labs offer a space for reflection, ideation, and design before interventions are introduced into clinical practice. Activities include mapping material flows, identifying problem areas, generating possible innovations, and assessing feasibility in relation to clinical, regulatory, and organisational constraints.

Clinical Living Labs

Clinical Living Labs focus on the execution of concrete, small-scale interventions within real-life clinical settings. They are embedded within specific departments, wards, or care pathways and operate under regular hospital conditions. Their primary purpose is to analyse and test medical circular interventions in practice and to generate empirical insights into their feasibility, impact, and potential for scaling. Clinical Living Labs enable learning-by-doing through iterative experimentation, monitoring, and evaluation.

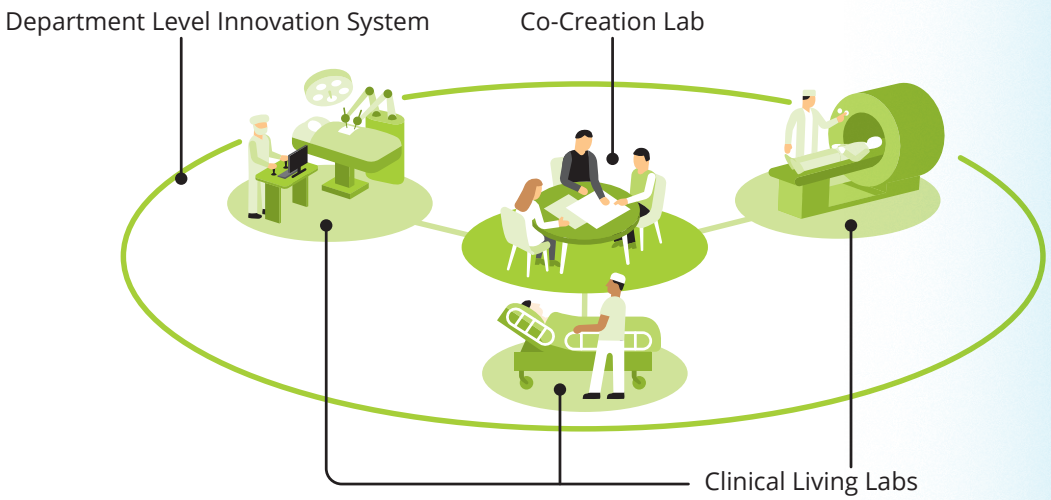


Figure 7: Co-Creation Lab and Clinical Living Labs

Illustration: © Marc Kolle (2026). This illustration is not licensed under the Creative Commons licence applicable to the text of this publication.

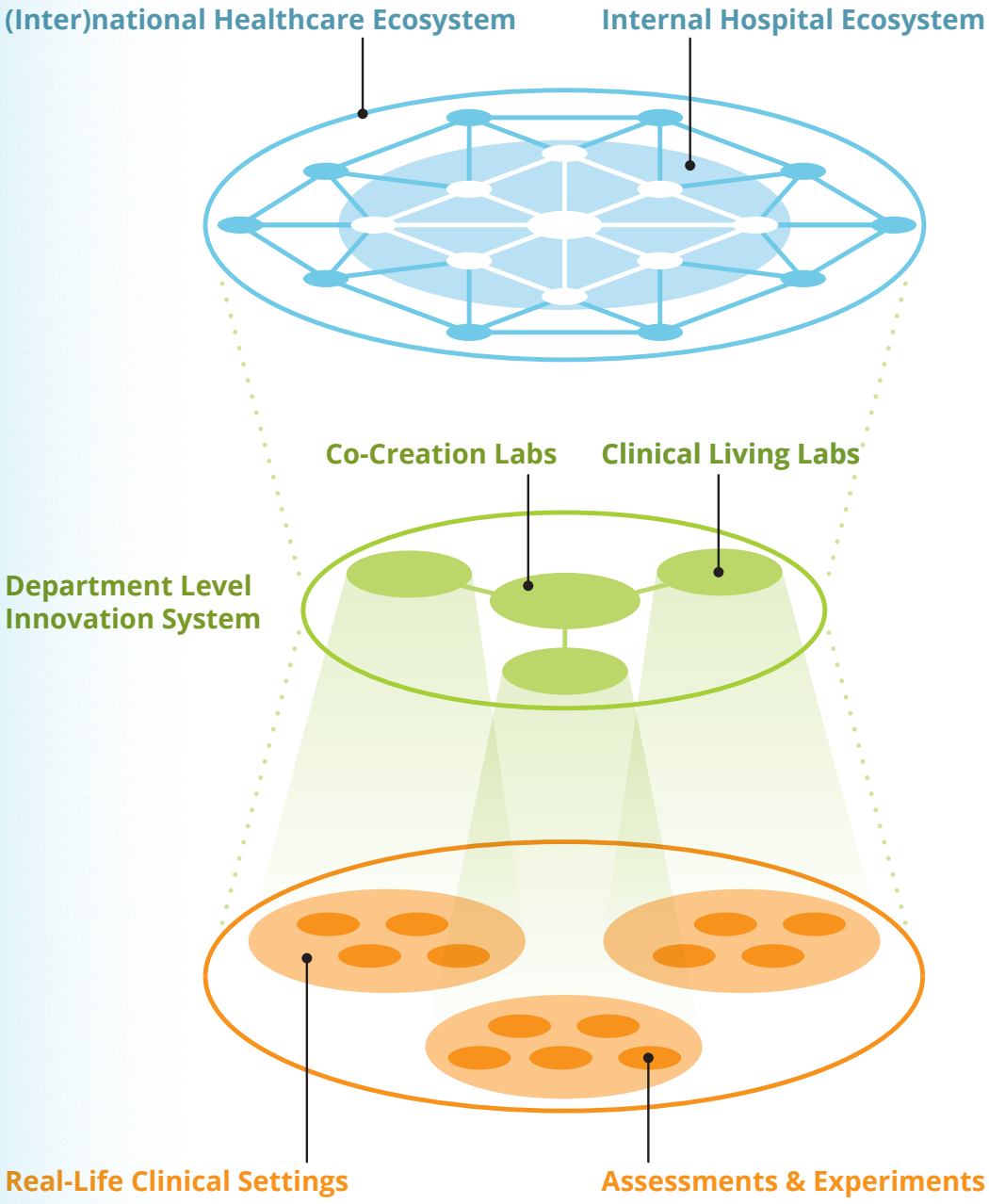
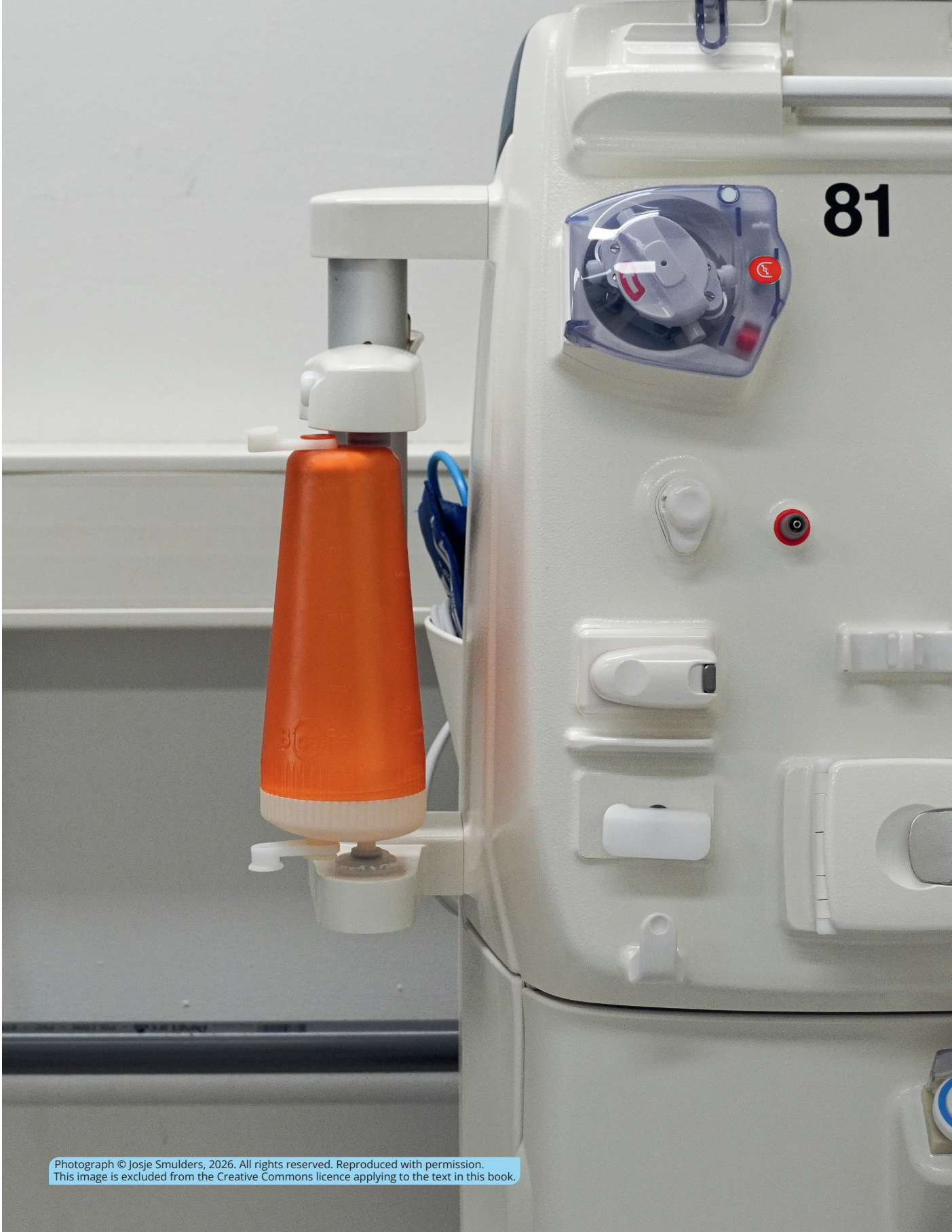


Figure 8: Multilevel Framework

Illustration: © Marc Kolle (2026). This illustration is not licensed under the Creative Commons licence applicable to the text of this publication.



Photograph © Josje Smulders, 2026. All rights reserved. Reproduced with permission.
This image is excluded from the Creative Commons licence applying to the text in this book.

Case Example
Reusable Bicarbonate Cartridge for Hemodialysis

Hemodialysis is a life-sustaining therapy for patients with kidney failure, but it is also a resource-intensive process because of its high consumption of water, energy, chemicals, and disposable medical products. One such product is the bicarbonate cartridge used to prepare dialysate fluid during treatment. In the Netherlands alone, approximately 812,000 cartridges are used each year. A graduation project (Smulders, 2026), conducted at TU Delft in cooperation with University Medical Center Utrecht, investigated opportunities to reduce the environmental impact of these cartridges. Adopting a systems-oriented and transition-design perspective, the project analysed the wider dialysis ecosystem, including clinical workflows, hygiene standards, logistics, regulations, procurement processes, waste management, and stakeholder responsibilities. The analysis showed that sodium bicarbonate production accounts for approximately 56% of the cartridge's climate impact, while a waste audit revealed that around 40% of the bicarbonate powder remains unused and is discarded after treatment. These findings informed the identification of requirements for circular alternatives, taking into account strict medical regulations, hygiene requirements, contamination risks, storage limitations, workflow constraints, and resistance to change in highly regulated hospital environments. In response, the project developed "Bicare," a reusable bicarbonate cartridge made from polysulfone and designed to withstand repeated high-level disinfection procedures. Rather than being discarded after a single use, cartridges would be collected, cleaned, refilled, relabelled, certified, and redistributed for reuse. Implementing such a system would require alignment among a wide range of stakeholders, including nurses, pharmacists, infection prevention specialists, sterilization departments, procurement staff, waste management services, and external reprocessing partners.

Chapter 6

Medical Circular Living Lab Process





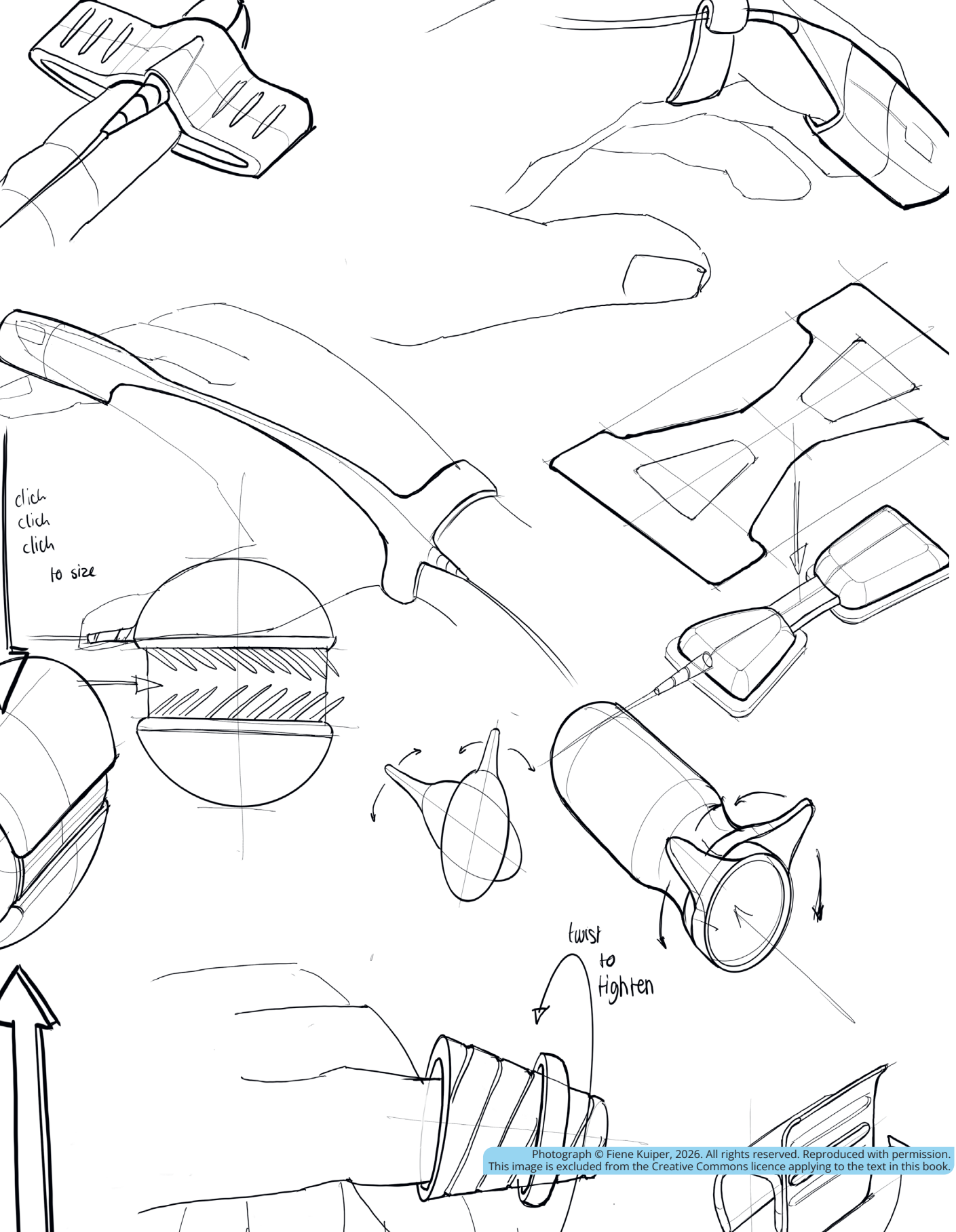
Photograph © Jan Tsai, 2026. All rights reserved. Reproduced with permission.
This image is excluded from the Creative Commons licence applying to the text in this book.

Introduction

The establishment and operation of Medical Circular Living Labs (MCLLs) follow a structured and iterative process that enables stakeholders to co-create, test, and scale circular healthcare innovations within real clinical environments. The eight-step process presented in this guidebook is inspired by a similar approach presented in (Dijkstra and Joore, 2025). However, that process was specifically focused on urban living labs, whereas this guidebook is focused on Medical Circular Living Labs. This means that the approach has been substantially modified to reflect the complex nature of the hospital environment and medical innovation processes.

The process is based on a systemic, multilevel design perspective, as described in the previous chapter. Circular healthcare innovation rarely concerns a single product or intervention; instead, it involves changes in clinical practices, procurement systems, logistics, value chains, and regulatory frameworks. For this reason, the MCLL process operates simultaneously on three interconnected levels: The (inter)national healthcare and hospital ecosystem (top level), the department-based innovation system (middle level), and the real-life clinical settings (bottom level).

Across these levels, the step-by-step process guide stakeholders through a cycle of determining the long-term circularity ambition, creating the foundation for the actual development of the MCLL (Phase A). When the MCLL is established, the next phase focusses on designing and executing interventions, assessments and experiments (Phase B). The next phase is about evaluation of the results of these interventions, and strategic alignment with the overall perspective (Phase C), and the cycle is finished with a focus on systemic integration and scaling (Phase D). These four overall phases are depicted in Figure 9, moving in and out of the three system levels: A from top to middle, B from middle to bottom, C from bottom to middle and D back again from middle to top. This process functions as an iterative innovation cycle where insights generated during one innovation cycle continuously feed back into new rounds of interventions.



Photograph © Fiene Kuiper, 2026. All rights reserved. Reproduced with permission.
This image is excluded from the Creative Commons licence applying to the text in this book.

Phase A (top to middle) focuses on bringing together relevant stakeholders within the healthcare ecosystem to formulate a shared ambition and vision for medical circularity. This phase involves initiating the MCLL by defining vision and coordination, mapping stakeholders, and securing funding and resources. It also includes creating the Living Lab through site selection, setup, and identifying environmental hotspots. Together, these steps establish the vision, governance, partnerships, resources, and operational foundation needed to launch the Living Lab.

Phase B (middle to bottom) focuses on translating the shared long-term circularity challenge into concrete interventions in clinical practice. This includes developing circular experiments through co-creation, selection, and preparation for validation, followed by testing in real-life settings, including procedural preparation, ethical and regulatory approval, and clinical validation. Together, these steps enable the development and evaluation of circular healthcare solutions in practice.

Phase C (bottom to middle) focuses on assessing experimental outcomes and aligning them with the broader vision and goals of the MCLL. Test results are evaluated to decide whether to iterate or scale, after which outcomes are compared with the original vision to identify remaining gaps. Insights from real-life experiments are systematically collected, evaluated, and discussed with stakeholders. By considering trade-offs between environmental impact, costs, organisational factors, and clinical performance, solutions can be refined or better aligned with organisational strategies and sustainability objectives.

Phase D (middle to top) focuses on embedding successful interventions into the broader healthcare system and using lessons learned to inform policy, procurement, and clinical practice. Insights from experiments are reflected upon and institutionalized, while recognizing that system-level changes—such as new regulations—may be required to enable adoption. Impact is monitored to guide next steps, including scaling, implementation, commercialization, and replication across departments, institutions, and health systems, often involving stakeholders beyond the MCLL.

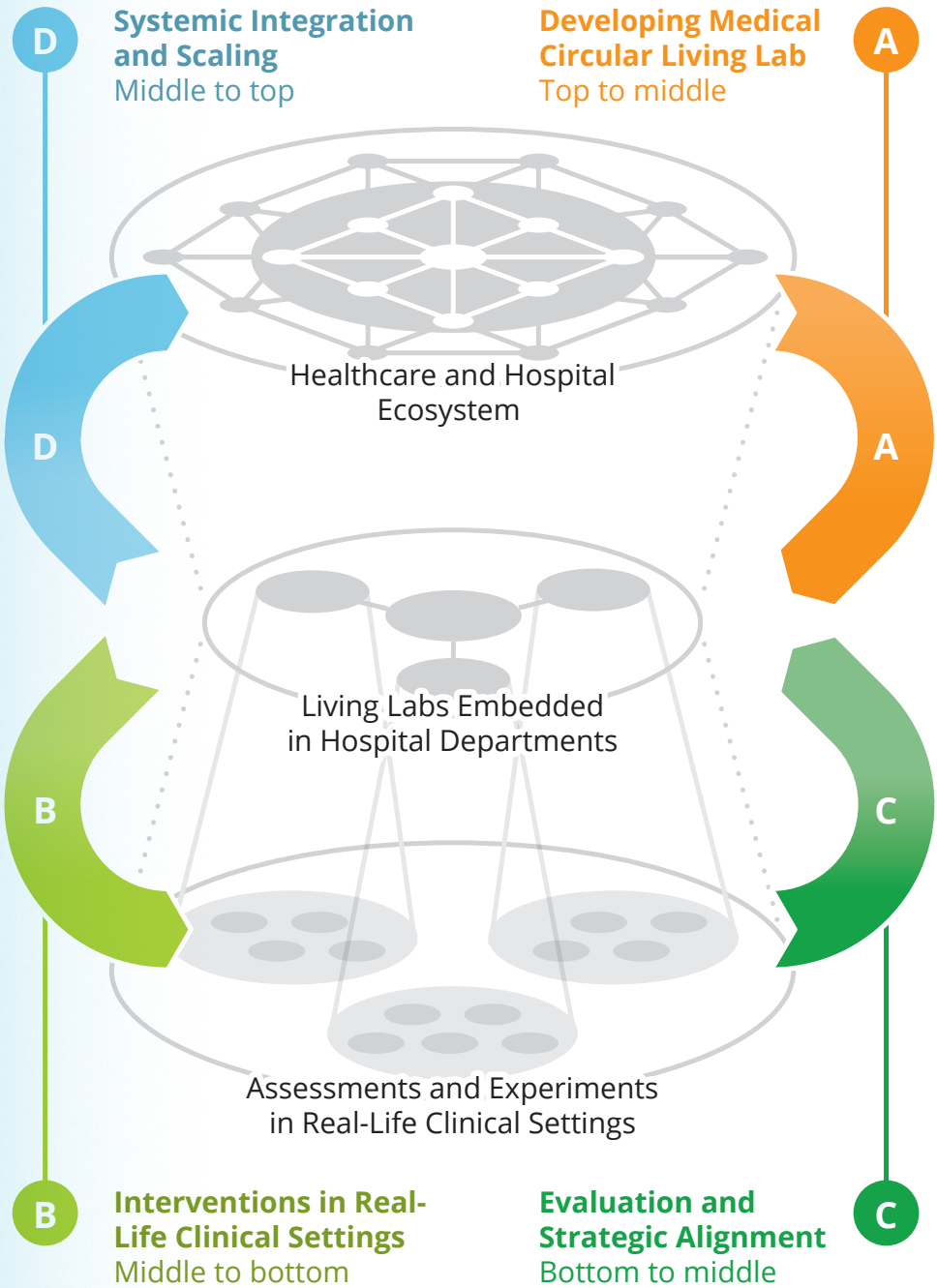


Figure 9: Mutual Interaction Between System Levels

Illustration: © Marc Kolle (2026). This illustration is not licensed under the Creative Commons licence applicable to the text of this publication.

Eight Step Innovation Process

The four overall phases can be broken down into two steps each, resulting in a total of eight steps. Each step consists of several key activities that can help to structure the deployment of the MCLL, from initial vision formation to systemic implementation and replication. Each step describes a specific phase in the development and operation of the MCLL and includes one or more key activities. For each activity the objective, description, core activities, and deliverables are specified, allowing practitioners to understand both the purpose and the practical tasks involved. The eight steps are depicted in Figure 10 and 11.

Step 1) Determine Circular Ambition

In Step 1, a shared vision for circular healthcare innovation is established by defining sustainability goals, governance structures, stakeholder roles, and the resources required to support collaboration within the Medical Circular Living Lab (MCLL).

Step 2) (Re)Design MCL Plan

In Step 2, the organisational and physical infrastructure of the MCLL is developed by selecting clinical sites, forming multidisciplinary teams, and identifying environmental hotspots with the greatest potential for circular improvement.

Step 3) (Re)Design Circular Interventions

In Step 3, circular interventions are collaboratively designed and refined through co-creation, systems thinking, and iterative design processes to ensure that solutions are feasible, clinically relevant, and environmentally impactful.

Step 4) Test and Experience Interventions

In Step 4, circular interventions are prepared, implemented, and validated in real clinical environments while ensuring ethical approval, operational readiness, patient safety, and effective data collection throughout the testing process.

Step 5) Evaluate Interventions

In Step 5, the performance and outcomes of the interventions are evaluated by analysing environmental, clinical, operational, and user-related results to determine whether solutions should be scaled, improved, or redesigned.

Step 6) Integrate and Contextualise

In Step 6, the experimental outcomes are interpreted in relation to the original circular vision and strategic ambitions of the MCLL, identifying where goals have been achieved and where additional action is still required.

Step 7) Evaluate and Learn

In Step 7, practical experiences and experimental outcomes are translated into structured organisational learning through reflection on collaboration processes, innovation practices, and lessons learned across stakeholders and institutions.

Step 8) Monitor Systemic Impact

In Step 8, the broader environmental, economic, and organisational impact of the interventions is continuously monitored while supporting their long-term implementation, scaling, commercialisation, and replication across healthcare systems.

Iterative Development Cycle

After Step 8, the process does not end but enters a new iteration cycle. Based on the lessons learned, monitored impacts, and insights gained throughout the previous cycle, the circular ambitions and strategic goals of the MCLL are revisited, refined, or expanded. From there, the process moves again through all eight steps — redesigning plans and interventions, testing and evaluating new solutions, and continuously learning and adapting. In this way, the MCLL functions as an iterative and evolving innovation process that continuously supports circular transition and systemic improvement within healthcare systems.

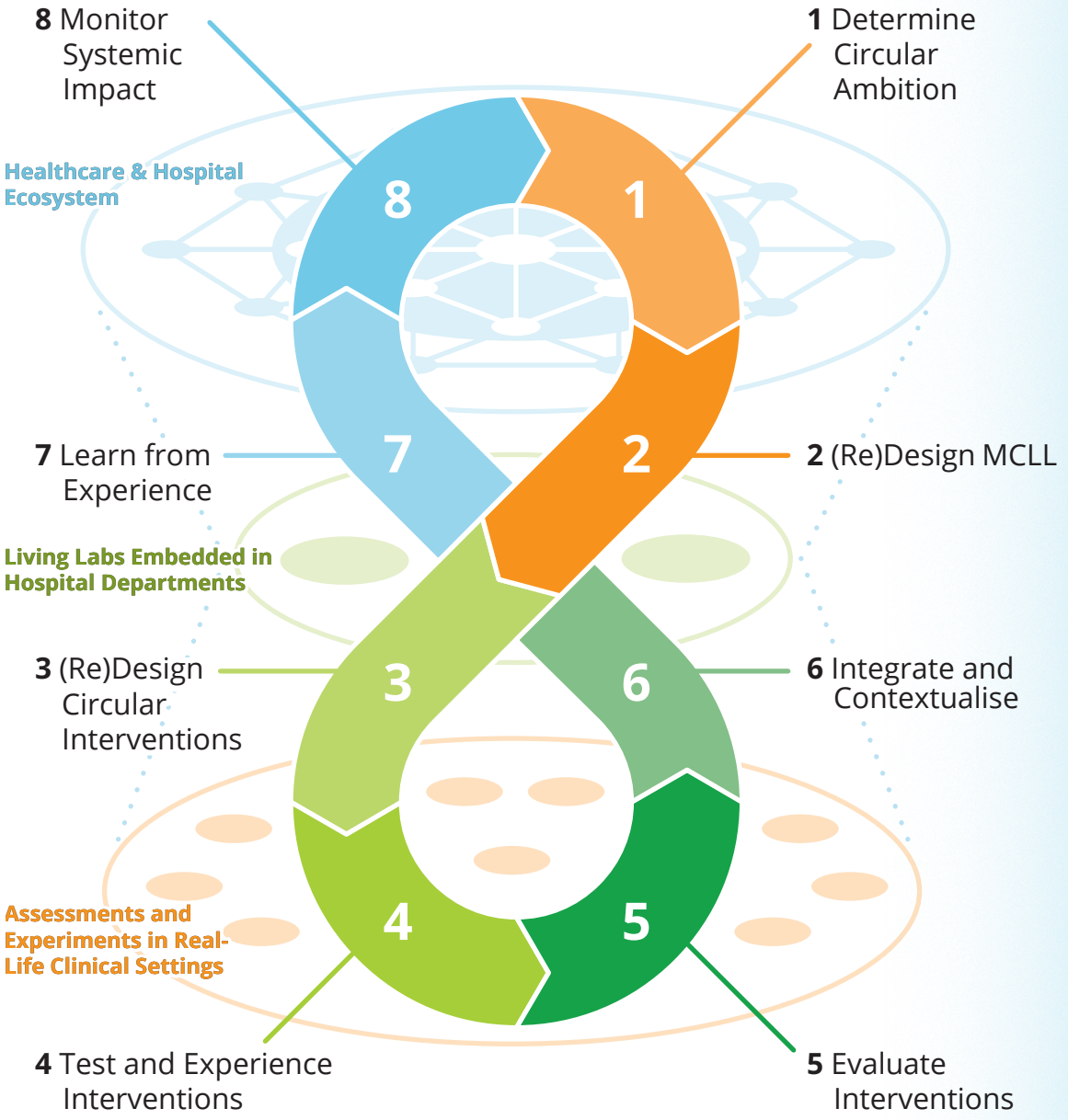


Figure 10: Medical Circular Living Lab Process combined with Multilevel Framework

Illustration: © Marc Kolle (2026). This illustration is not licensed under the Creative Commons licence applicable to the text of this publication.



Figure 11: Medical Circular Living Lab Process

Illustration: © Marc Kolle (2026). This illustration is not licensed under the Creative Commons licence applicable to the text of this publication.

Step 1

Determine Circular Ambition


8
1
Determine
Circular
Ambition
7
2
3
6
4
5

Introduction Step 1

This phase establishes the foundation for the MCLL. It defines the shared vision, structure, and coordination mechanisms that will guide collaboration. The focus is on first identifying and agreeing on clear sustainability objectives. This is needed to align and engage all key stakeholders at an early stage. Creating trust, shared purpose, and coordination is key. The intended result is an mutually agreed framework that enables effective collaboration within the hospital ecosystem.

Key Activity 1.1: Stakeholder Mapping and Engagement

Objective

To identify, analyse, and actively engage all relevant stakeholders, ensuring that the MCLL includes the necessary perspectives, expertise, and commitment required for effective co-creation and implementation.

Description

In this activity, stakeholders are mapped and analysed to understand their roles, interests, and influence within the hospital. Based on this, engagement strategies are defined and initial interactions are organised to involve stakeholders in the process and establish collaboration. Governance models in LLs often feature a quadruple or quintuple helix approach, integrating public, private, academic, and civil society stakeholders, sometimes also including the environment (Merino-Barbancho et al., 2023).

Activities

- Identify core partners: hospitals, academic partners and students, industry (Medical technology and consumables suppliers, material companies, recycling and waste management), patient organisations, and government.
- Map internal hospital stakeholders: clinical doctors, nurses, procurement, sustainability officers, green teams, management, financial, infection prevention and safety, and others.
- Conduct engagement workshops to define shared goals and expectations.

Deliverable

- Stakeholder Engagement Plan

Key Activity 1.2: Define Circularity Vision and Scope

Objective

To establish a shared and clearly articulated vision, scope that aligns stakeholders around common circularity goals and provides a coherent framework for collaboration and governance.

Description

In this activity, stakeholders jointly define the overall vision, scope, and organisational setup of the MCLL. This includes clarifying circularity ambitions, determining the focus areas, and establishing how the Living Lab will be coordinated and governed. The outcome provides a shared direction and a clear structure for collaboration throughout the MCLL process.

Activities

- Articulate clear sustainability and circularity objectives: e.g., reducing environmental footprint of medical consumables and instruments.
- Set up a coordination charter with representatives from all key partners.

Deliverable

- Medical Circular Vision & Coordination Charter

Key Activity 1.3: Secure Funding and Resources

Objective

To secure the financial, human, and infrastructural resources required to establish and sustain the MCLL, ensuring feasibility, continuity, and capacity to execute planned activities.

Description

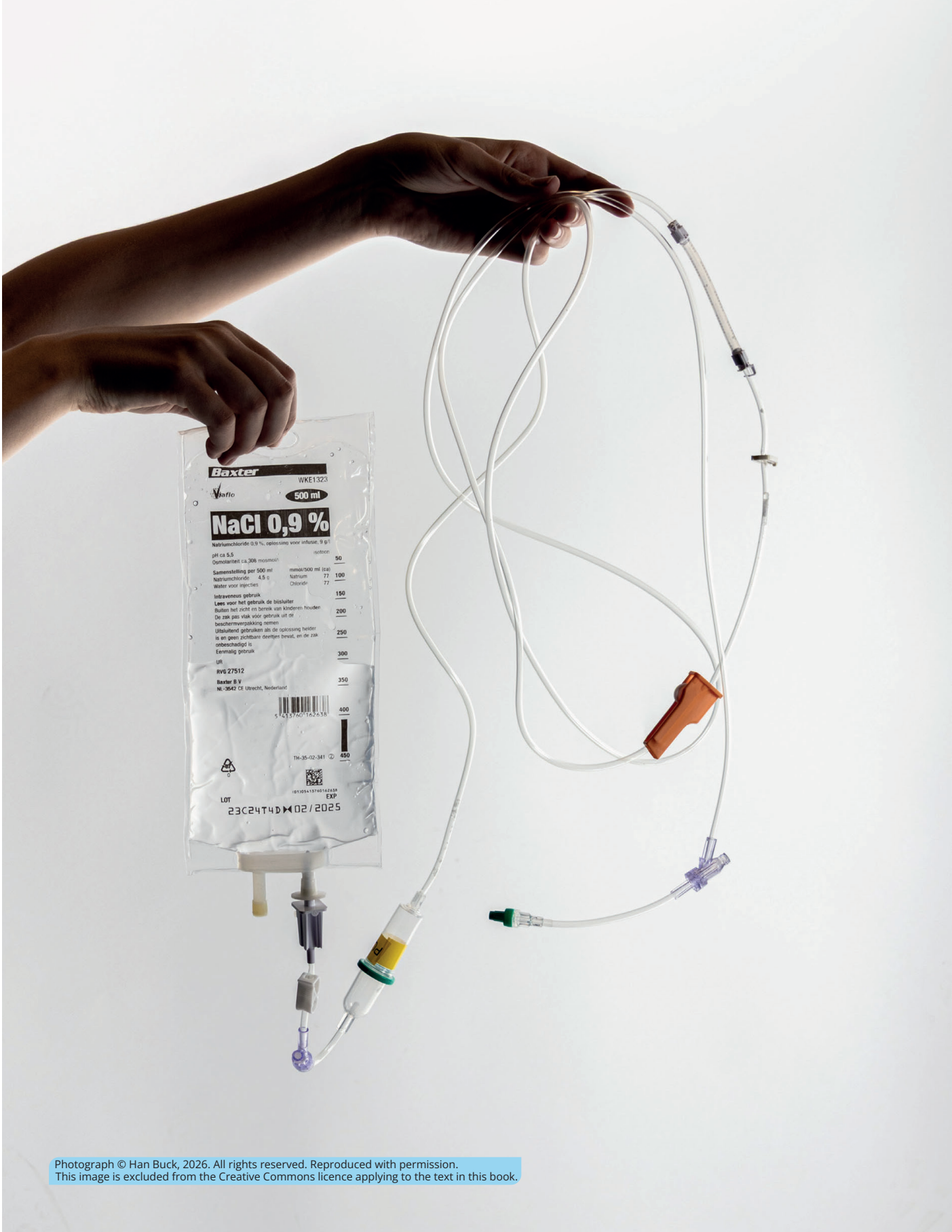
In this activity, available funding opportunities are explored, and resources are mobilised to support the MCLL. This includes identifying financial sources, allocating internal capacity, and organising the necessary infrastructure to enable the planned activities and ensure continuity of the Living Lab.

Activities

- Estimate financial, human, and infrastructural needs.
- Identify funding sources: EU/ national research project grants, innovation funds, or industry co-funding, in-kind and real-costs contributions.
- Cross-fund with hospital foundations and medical technology companies and consortia to enable procurement of circular prototypes.
- Roll out the idea and set-up of the MCLL in each of the targeted departments.

Deliverable

- Budget and Resource Plan



Photograph © Han Buck, 2026. All rights reserved. Reproduced with permission.
This image is excluded from the Creative Commons licence applying to the text in this book.

Case Example
Circular Infusion Bags

This graduation project by Buck (2025) explored how single-use infusion bags in hospitals could be redesigned to reduce plastic waste and improve recyclability. The project focussed on infusion and dialysis bags used in Intensive Care Units (ICUs), where plastic consumption and waste generation are particularly high. ICU patients generate approximately 17 kg of waste per day, of which around 23% consists of fluid bags and tubing. Infusion and dialysis bags together account for roughly 22 tonnes of plastic waste annually, most of which is incinerated despite having potential of being recyclable.

The study mapped the use of infusion bags across Erasmus University Medical Center. Analysis identified small base-solution IV bags as the primary hotspot, with more than 709,000 units used annually, representing approximately 12.8 tonnes of plastic waste per year. Large IV bags represent about 24,000 units annually, contributing an additional 3.4 tonnes of plastic waste. Material complexity was identified as the primary barrier to recycling. Existing infusion bags combine multiple incompatible plastics and rubber components, making mechanical recycling impossible. Most used infusion bags are treated as medical waste and sent for incineration. In one partial recycling workflow for dialysis bags, nurses must manually cut off the connectors before disposal — a repetitive and ergonomically problematic task. A special process was designed so this can be done during the quite hours of a shift in the ICU.

The project resulted in “Ivy,” a redesigned infusion bag system that enables full recyclability while maintaining existing hospital workflows. The redesign focussed on material compatibility, simplification of the connector system, reduction of material complexity, improved ergonomics, and compatibility with existing manufacturing and sterilization systems. Ivy eliminates the need for nurses to manually separate components before disposal by enabling the entire bag to be recycled as one compatible material stream. This case demonstrates how relatively small product-level interventions can contribute to circular healthcare when combined with a systemic understanding of hospital operations, manufacturing constraints, and recycling infrastructures.

Step 2

(Re)Design Medical Circular Living Lab


8
1
7
2
(Re)Design
MCLL
3
6
4
5

Introduction Step 2

In this step, the MCLLs take physical and organisational shape. Infrastructure and site selection are secured, and hospital departments with high environmental impact are identified. Selected clinical contexts ensure practical relevance and ownership of innovation. Sustainability assessments such as Life Cycle Analyses (LCA), Material Flow Analysis (MFA) and waste audits help select intervention areas with the greatest potential impact. This phase turns the circular vision into a functioning lab ecosystem - one that connects strategy, data, and daily hospital operations.

Key Activity 2.1: Site Selection and Infrastructure Setup, Team formation

Objective

To establish the physical financial and organisational infrastructure of the MCLL, including selecting appropriate locations, setting up facilities, resource planning, and forming of multidisciplinary teams for executing relevant assessments and experiments.

Description

In this key activity, the MCLL is operationalised by selecting suitable clinical locations, setting up the necessary physical and organisational infrastructure, and forming action-oriented multidisciplinary teams. Practical arrangements are made to enable active collaboration, experimentation, and coordination within the hospital environment.

Activities

- Determine appropriate lab structure. For instance, one Co-Creation Lab as a central innovation hub, with several Clinical Living Labs as department-based locations for testing and validation of circular interventions in a real-life clinical environment
- Allocate budgets including: Infrastructure budget (space, IT systems, monitoring tools) ; Personnel budget (PhD candidates, postdocs, students, technical staff, medical staff, MCLL coordination, management); Budget for prototyping, testing and validating pilot interventions.
- Team Formation. Select personnel and assign tasks and responsibilities. Do this for the overall MCLL as well as for each of the involved departments. Determine who will be coordinator(s) of the Co-Creation Lab and the Clinical Living Labs, who will be the relevant hospital and faculty advisors, who are the clinical champions.
- Identify the environmental hotspots for circular improvements.
- Establish a Co-Creation space within the hospital or academic partner site with open, collaborative workspace design, both physical and virtual.
- Embed Clinical Living Labs within departments with high potential for circular interventions based on the hotspot analysis. Whether or not these are separate Living Labs, or all integrated within the Co-creation Lab, depends on the set-up of the entire project.
- Provide meeting and co-design spaces, data monitoring and analysis tools, access to relevant clinical equipment

Deliverable

- Functional infrastructure
- Resource plan
- MCLL core team and active partners

Key Activity 2.2: Identify Environmental Hotspots

Objective

Identify and prioritise high-impact areas within clinical environments where circular interventions can generate the greatest environmental and systemic benefits.

Description

Environmental hotspots within the selected clinical settings are identified and analysed. Data on material use, waste streams, and environmental impact are collected and assessed to determine priority areas where circular interventions can have the greatest effect.

Activities

- Organise a regular communication and meeting structure with representatives of the partners from the project responsible for selection of the intervention cases.
- Detail the hotspot analysis performed for the selected clinics including the treatments and procedures selected within these clinics.
- Conduct (additional) sustainability assessments in each Clinical Living Lab, combined with Life Cycle Assessments (LCA), Material Flow Analyses (MFA), waste audits.
- Select high-impact consumables as potential intervention cases. Of course, the number and distribution depend on the specific project context.

Deliverable

- Environmental Hotspot Analysis & Case Selection

Case Example
Finnish Living Lab Network in Healthcare

Santonen et al. (2024) position Living Labs in healthcare as structured open innovation ecosystems that support systematic co-creation and innovation development within real-life healthcare settings. Rather than viewing Living Labs merely as environments for experimentation, the study emphasizes that successful Living Labs depend on clearly organised processes, facilitation methods, stakeholder management practices, and structured innovation phases.

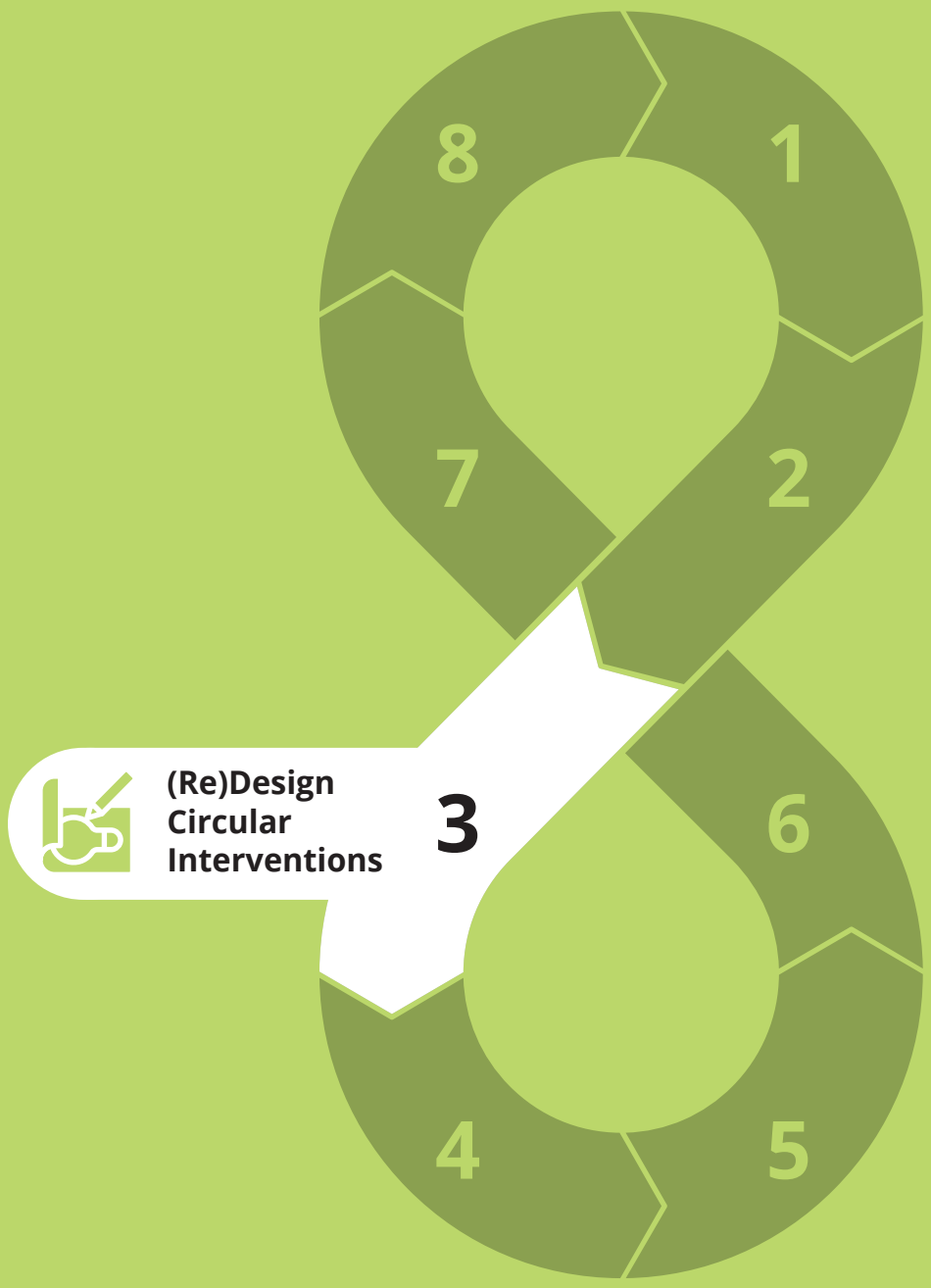
A central contribution of the study is its articulation of the multi-actor value proposition of Living Labs. The authors explain that Living Labs simultaneously create value for different stakeholder groups—including healthcare organisations, companies, researchers, and public actors—by enabling collaboration, knowledge exchange, iterative development, and shared learning. This multi-actor value creation is considered essential for addressing complex healthcare and societal challenges.

The study further highlights the importance of aligning Living Lab activities with innovation maturity, expected outcomes, and implementation goals. According to the authors, effective Living Labs require explicit structuring of co-creation, testing, evaluation, and implementation phases, combined with clear definitions of stakeholder roles and responsibilities. Without such structured coordination and shared understanding of value creation, Living Lab activities risk remaining exploratory rather than generating scalable and transformative innovation outcomes.

The case therefore positions Living Labs as impact-oriented innovation infrastructures that can bridge the gap between experimentation and real-world implementation within complex healthcare ecosystems.

Step 3

(Re)Design Circular Interventions


8
1
7
2
6
4
5
(Re)Design
Circular
Interventions
3

Introduction Step 3

In this phase, multidisciplinary teams co-design circular interventions through design thinking, systems mapping, and iterative workshops. The goal is to translate environmental challenges into concrete product and process concepts, guided by the 10R circular principles. Through structured co-creation and selection processes, ideas are refined into feasible, test-ready concepts. This phase balances innovation freedom with practical decision-making, ensuring that chosen interventions are both ambitious and implementable.

Key Activity 3.1: Co-Creation of Circular Interventions

Objective

To collaboratively design promising circular interventions with stakeholders, ensuring that solutions are context-relevant, feasible, and aligned with clinical, environmental, and organisational needs.

Description

This activity focuses on the collaborative development of circular intervention concepts through structured co-creation processes. Stakeholders—including clinical staff, researchers, industry partners, and other relevant actors—are brought together in workshops and design sessions to identify opportunities, generate ideas, and translate these into initial circular concepts. These concepts are iteratively refined, considering feasibility, safety, and environmental impact. The result is a set of promising circular interventions ready for further development and selection.

Co-creation within a Medical Circular Living Lab (MCLL) is a collaborative and iterative process in which diverse stakeholders jointly develop, test, and refine solutions to complex challenges. It involves doctors and nurses, hospital staff (e.g. purchasing, GSA, management), researchers and students, industry partners, and, where relevant, policymakers. Rather than designing solutions in isolation, co-creation ensures that interventions are grounded in real-world needs, constraints, and opportunities. This leads to solutions that are not only technically feasible, but also clinically relevant, operationally workable, and broadly supported.

The co-creation process is inherently iterative: ideas are explored, tested in practice, and continuously improved through feedback and shared learning, often looping through multiple development cycles. This helps identify barriers, align stakeholder interests, and build shared ownership. By embedding co-creation in real clinical environments, MCLLs enable the development of solutions that can be implemented, scaled, and sustained within the hospital and its wider ecosystem.

Activities

- Form a core co-creation team for each intervention case (designer, researcher, clinicians, industry partners)
- Conduct multi-perspective analyses using systems thinking and design thinking
- Explore 10-R circular strategies for selected products and systems
- Facilitate design sprints and co-creation workshops to prototype circular interventions

Deliverables:

- Promising intervention cases
- Portfolio of circular intervention concepts

Key Activity 3.2: Solution Selection and Pre-Validation Preparation

Objective

To narrow down initial co-created concepts into specific, feasible intervention directions that are ready for ethical and regulatory submission and potential real-world testing.

Description

Following the initial co-creation and ideation phase in Step 3.1, a structured selection process is undertaken to determine which circular intervention concepts will advance toward prototyping and testing. During this process, proposed intervention directions are assessed and prioritised based on criteria such as technical feasibility, clinical relevance, environmental impact, stakeholder support, and alignment with existing hospital systems and practices. The process also involves converging from a broad range of ideas toward a clearly defined intervention concept, including preliminary workflows, product designs, or system adaptations where appropriate. In parallel, detailed documentation is prepared to support subsequent ethical and regulatory submissions (see Step 4.2), including a description of the intervention rationale, stakeholder roles and responsibilities, safety considerations, and proposed data collection procedures. This activity serves as an important design decision gateway, ensuring that only sufficiently developed, supported, and feasible interventions proceed to the testing and validation phase.

Activities

- Conduct intervention feasibility assessments with clinical and technical experts.
- Facilitate a multi-stakeholder prioritization workshop to align on selected solution paths.
- Refine documentation for ethical submission, including risk-benefit considerations and implementation scenarios.
- Ensure early alignment with infection control, legal teams, and IT (for data-related interventions).

Deliverable

- Refined intervention concept for each case
- Pre-validation dossier



Photograph © Rogier Bos, 2026. All rights reserved. Reproduced with permission.
This image is excluded from the Creative Commons licence applying to the text in this book.

Case Example

Material Flow Analysis Erasmus University Medical Center

As part of the ESCH-R project, researchers at Erasmus University Medical Center conducted a Material Flow Analysis (MFA) of medication use in a 50-bed Intensive Care Unit (ICU), demonstrating how MFA can support targeted sustainability strategies in critical care settings. The study, led by Klasen et al. (2025), analysed all medications delivered to the ICU, including active pharmaceutical ingredients (APIs), excipients, dosage forms, and associated packaging materials. The analysis showed a total annual medication inflow of 234,337 kg, consisting of 194,411 kg of medication content and 39,923 kg of packaging materials. APIs accounted for only 5,287 kg (2.3%) of the total mass, while the majority originated from excipients and fluid components. On average, ICU patients received 89.5 medication units per day, corresponding to approximately 5.0 kg of medication and generating 1.7 kg of packaging waste per patient each day.

The MFA identified dialysis-related fluids and disposable materials used for Continuous Renal Replacement Therapy (CRRT) as major contributors to material consumption and waste generation. Waste outflows included 194,413 kg discharged into the sewage system, 21,894 kg incinerated, and 18,030 kg recycled, mainly consisting of CRRT infusion bags.

Based on these findings, the study proposed several circular interventions to reduce the environmental footprint of intensive care, including minimizing packaging waste, improving recycling practices, promoting oral medication where clinically appropriate, and developing more concentrated fluid formulations to reduce overall material use and waste generation.

Step 4

Test and Experience Interventions


8
1
7
2
3
6
5
4
Test and
Experience
Interventions

Introduction Step 4

In this phase, concepts are tested and validated in real clinical environments. Ethical approval, detailed testing protocols, and coordination with hospital staff should ensure that pilots run safely and effectively. Testing focuses on environmental, economic, and clinical performance, while gathering feedback from users and partners. Impact monitoring ensures that circular and sustainability targets are met. This phase bridges design and implementation, allowing the MCLLs to learn how circular innovations perform under real conditions and to identify adjustments needed before wider adoption.

Key Activity 4.1: Prepare Testing Procedure

Objective

To translate the ethically approved intervention concepts into a detailed, operational testing protocol, ensuring clinical feasibility, safety, stakeholder alignment, and logistics readiness in the intended care setting.

Description

This step operationalises the transition from approval to implementation. While Step 4.2 below ensures compliance with legal and ethical frameworks, Step 4.1 is about clinical and logistical readiness. It includes:

- Finalizing when, where, and how the intervention will be tested.
- Clarifying responsibilities and workflows.
- Ensuring all necessary materials, staff, and support are in place.
- Anticipating barriers and preparing fallback options.

Testing in hospitals is complex due to scheduling, patient safety, infection control, and multi-stakeholder coordination. This step ensures the test is well-integrated into the daily routine, minimizing disruption while maximizing data quality and stakeholder engagement.

Activities

Develop a Testing Protocol, including:

- Scope, target population, timeline, and location(s)
- Description of workflows and staff roles
- Inclusion/exclusion criteria if patients are involved

Schedule Testing Phases and allocate time slots in clinical settings.

Staff Briefing and Training

- Ensure clinical teams understand procedures and objectives.
- Confirm infection prevention and safety protocols.

Prepare Materials and Resources

- Circular products or systems to be tested
- Measurement tools (e.g. LCA indicators, user satisfaction forms)
- IT/data capture systems if needed

Risk Management Planning

- Define possible failure points or delays and mitigation measures.

Dry Run or Simulation

- Pre-test in a controlled setting to detect issues early.

Deliverables

- Testing Protocol (including objectives, scope, and methodology)
- Operational Testing Plan (workflow integration, roles, and responsibilities)
- Data Collection Plan (including KPIs and measurement methods)
- Risk Assessment and Mitigation Plan (including patient safety and infection prevention considerations)

Key Activity 4.2: Obtain Ethical and Regulatory Approvals

Objective

To ensure that all interventions comply with ethical standards, legal requirements, and hospital regulations, enabling safe and approved testing within clinical environments.

Description

In this activity, the necessary ethical approvals and regulatory clearances are obtained to enable testing within the clinical environment. Relevant requirements are identified, documentation is prepared, and approval procedures are followed in collaboration with hospital committees and regulatory bodies. This ensures that all interventions can be tested in compliance with legal, ethical, and safety standards.

Activities

- Align with medical ethics committees and hospital regulations.
- Secure permissions for data collection, waste audits, prototyping, testing and validating within clinical environments.
- Ensure compliance with data protection and with infection prevention and patient safety standards.

Deliverable

- Ethical Approval Package

Key Activity 4.3: Testing and Validation in Clinical Setting

Objective

To test and validate circular interventions in real-life clinical environments, generating evidence on environmental, clinical, and economic performance.

Description

In this activity, circular interventions are implemented and tested within real clinical environments. The interventions are integrated into daily workflows, allowing stakeholders to observe how they perform under actual conditions. During this phase, data is collected on clinical feasibility, usability, environmental impact, and organisational implications.

Stakeholders closely monitor the implementation, capturing both quantitative results and qualitative feedback from users. Any issues or unexpected effects are identified and addressed where possible during the testing phase. This activity provides the evidence base required for the environmental, clinical, and organisational evaluations conducted in Step 5.

Activities

- Pilot the circular interventions in clinical practice.
- Collect quantitative performance data on environmental, clinical, operational, and economic indicators using predefined measurement methods and KPIs.
- Collect qualitative feedback from healthcare professionals, patients, and value-chain partners regarding usability, acceptance, clinical feasibility, and implementation experiences through observations, interviews, questionnaires, workshops, or other appropriate methods.
- Monitor implementation processes and document barriers, enabling factors, contextual influences, and unintended effects.
- Conduct validation with external value-chain partners (e.g., manufacturers and waste processors).
- Develop and validate business models for the new products, systems, and value chains.
- Investigate procurement requirements, operational procedures, and organisational protocols necessary for successful implementation of the new products and systems.

Deliverables:

- Testing and Validation Report
- Performance Dataset and Monitoring Results
- Potential business models
- Working procedures and protocols

Case Example
Digital Health Living Lab, Brighton

Fotis et al. (2023) examine how co-creation operates within a Digital Health Living Lab established by the University of Brighton. The case demonstrates how co-creation between patients, healthcare professionals, researchers, and developers supports the development of person-centred digital health solutions by grounding innovation activities in actual user needs, everyday healthcare practices, and lived experiences.

The study presents a structured approach for organizing and facilitating co-creation within Medical Living Labs. The authors describe a step-by-step process involving stakeholder engagement, needs identification, iterative development, real-life testing, and in-situ evaluation. They emphasize that co-creation is not a separate phase within innovation processes, but a continuous and iterative activity embedded throughout the full development and implementation trajectory.

The authors conclude that the Living Lab approach enabled rapid feedback loops between stakeholders, allowing digital health interventions to be continuously refined through real-world experimentation and user input. This iterative approach improved usability, relevance, and acceptance of the developed solutions while strengthening their implementation potential within healthcare practice.

At the same time, the case highlights several challenges characteristic of Medical Living Labs, including the coordination of diverse stakeholder groups, sustaining participant engagement over time, and balancing different expectations and priorities. Overall, the study demonstrates how structured co-creation within Living Labs can function as a promising approach for user-driven healthcare innovation and implementation-oriented system change.

Step 5
Evaluate Interventions



5 Evaluate Interventions

Introduction Step 5

After testing and validation in real-world clinical settings, the intervention is systematically evaluated using quantitative and qualitative evidence gathered during the experimentation phase. The aim is to establish a robust understanding of the intervention's performance before relating the results to the broader ambitions of the Medical Circular Living Lab in Step 6.

Evaluation takes place from two complementary perspectives. The first focuses on circularity and sustainability, assessing environmental impact reduction and the application of circular strategies. The second focuses on healthcare practice, assessing clinical performance, patient safety, usability, organisational implications, and implementation feasibility.

By combining quantitative performance data with qualitative stakeholder experiences, this step provides an evidence-based assessment of the intervention's strengths, limitations, and improvement opportunities, forming the basis for the strategic reflection and prioritisation activities conducted in Step 6.

Key Activity 5.1: Circularity and Sustainability Evaluation

Objective

To assess the environmental and circular performance of the intervention based on evidence gathered during testing and validation.

Description

This activity evaluates the extent to which the intervention contributes to circular economy objectives and environmental impact reduction. Assessment focuses on material flows, resource efficiency, waste reduction, emissions reduction, and the application of circular strategies throughout the healthcare value chain. The evaluation investigates whether the intervention successfully applies relevant 10-R circular strategies and generates measurable environmental and sustainability benefits compared with current practice.

Activities

- Analyse Life Cycle Assessment (LCA) results.
- Analyse Material Flow Analysis (MFA) outcomes and waste audits.
- Assess reductions in waste generation, material consumption, energy use, and CO_2 emissions.
- Evaluate application of relevant 10-R circular strategies.
- Identify environmental trade-offs and unintended sustainability impacts.
- Compare outcomes with predefined circularity and sustainability objectives and success criteria.

Deliverables

- Circularity and Sustainability Evaluation Report

Key Activity 5.2: Clinical and Organisational Evaluation

Objective

To assess the clinical feasibility, safety, usability, and organisational implications of the intervention within healthcare practice.

Description

This activity evaluates whether the intervention functions effectively within the realities of clinical care delivery and hospital operations. The evaluation considers implications for patient safety, infection prevention, workflow integration, staff activities, operational implications, and organisational feasibility.

The aim is to determine whether the intervention can realistically be implemented and maintained within the hospital environment while meeting required quality and safety standards.

Activities

- Assess patient safety outcomes and clinical performance.
- Evaluate infection prevention and regulatory compliance implications.
- Analyse workflow integration and operational impacts.
- Assess usability and acceptance among healthcare professionals and patients.
- Evaluate organisational implications, including staffing and training requirements.
- Assess procurement, logistics, and implementation feasibility.
- Assess economic implications, including implementation costs, operational costs, and potential cost savings.
- Identify implementation barriers, unintended operational consequences, and contextual factors influencing intervention performance.
- Compare outcomes with predefined clinical, organisational, and implementation requirements.

Deliverables

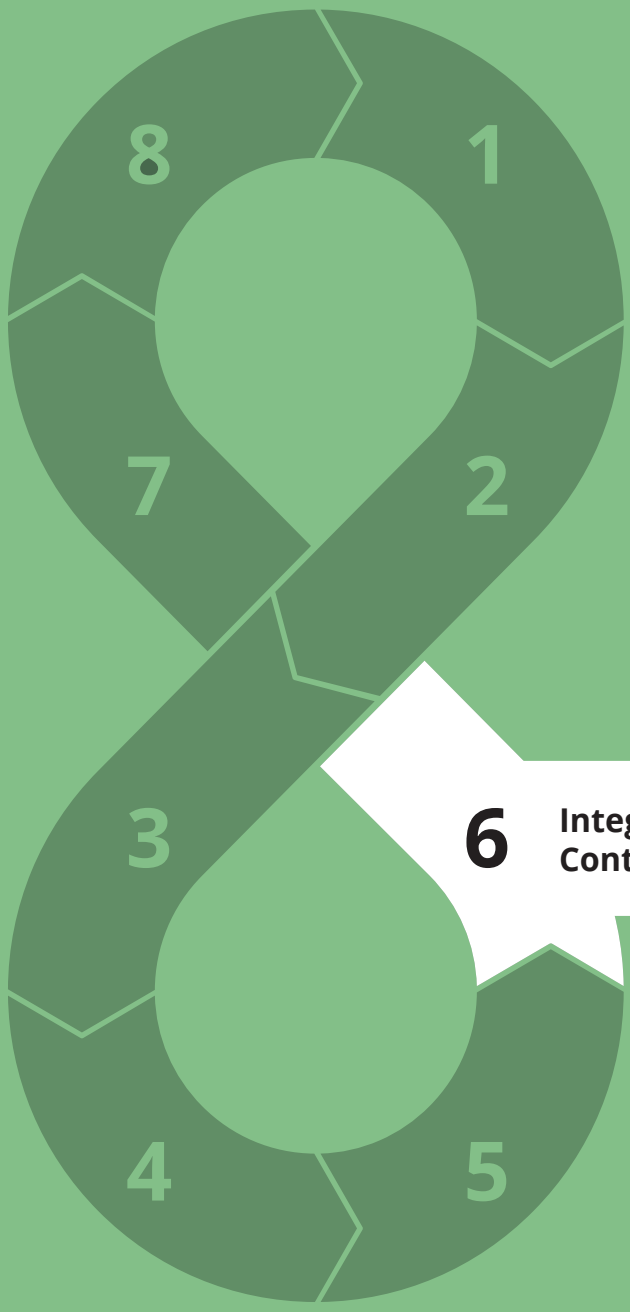
- Clinical and Organisational Feasibility Assessment
- User Experience and Acceptance Report

Case Example
Reducing PFAS in Medical Applications

As part of the Horizon Europe programme *Source to Seas – Zero Pollution 2030*, several Living Lab workshops explored strategies for reducing PFAS emissions from medical applications within European healthcare systems (Van Hulst et al., 2025). These workshops formed part of a stakeholder engagement process structured around the phases of identifying challenges, defining objectives, exploring alternatives, assessing consequences, and evaluating trade-offs. A central concern was the risk of "regrettable substitutions," whereby replacing PFAS could unintentionally introduce other harmful materials or negatively affect recycling and circularity practices. Stakeholders examined the use of PFAS in medical textiles, implants, catheters, inhalers, and anaesthetic gases, and evaluated four future governance scenarios for reducing PFAS emissions in healthcare. Discussions addressed challenges related to healthcare quality, environmental risks, affordability, circularity, transparency, regulatory uncertainty, and economic feasibility. This process identified governance gaps and systemic barriers related to PFAS use throughout the medical product lifecycle. The case illustrates how Living Lab methodologies can function as governance-oriented transition platforms that support systems thinking, stakeholder alignment, collective learning, and iterative co-creation around complex healthcare sustainability challenges. Rather than aiming to identify a single solution, the Living Lab approach facilitated the exploration of alternative transition pathways and their associated trade-offs. It also highlights the importance of lifecycle perspectives and iterative reflection in supporting long-term sustainability transitions within healthcare ecosystems.

Step 6

Integrate and Contextualise



6 Integrate and Contextualise

Introduction Step 6

This step answers the question – what do the results mean for the overall goal and vision in circular transition. It takes a broader perspective by reconnecting the outcomes with the original strategic intentions and systemic ambitions of the MCLL initiative.

This step ensures that the experimental results are interpreted not only in terms of technical or clinical performance, but also in relation to the long-term circular transition goals that guided the establishment of the MCLL.

Key Activity 6.1: Compare Results with the Original Vision

Objective

To assess how the outcomes of the tested circular interventions align with the original vision, sustainability objectives, and strategic goals defined at the beginning of the MCLL project.

Description

During the initiation phase (Step 1), stakeholders established a shared vision for the MCLL, including ambitions related to circularity, environmental impact reduction, and system-level change in healthcare practices. After the evaluation of individual interventions in Step 5, this vision is revisited and examined on how the tested interventions contribute to achieving these broader goals, in this way connecting the empirical results with strategy.

Activities

- Review the original MCLL vision and objectives defined during Step 1.
- Compare environmental, clinical, organisational, and economic results of the tested interventions with the intended sustainability and circularity goals.
- Discuss with key stakeholders how the outcomes contribute to the long-term transformation goals of the hospital or healthcare system.
- Identify areas where the interventions successfully support the original vision and where outcomes differ from expectations.
- Document insights regarding the alignment between experimental results and strategic objectives.

Deliverables

- Vision Alignment Review Report
- Documented comparison between experimental outcomes and the original MCLL vision

Key Activity 6.2: Determine What Elements of the Vision Still Need Attention

Objective

To identify which aspects of the original MCLL vision remain insufficiently addressed and determine priorities for future experimentation, development, or organisational change.

Description

While some interventions may demonstrate strong results, others may reveal that certain elements of the initial vision have not yet been fully achieved. These gaps may relate to technical feasibility, organisational barriers, regulatory constraints, stakeholder engagement, or broader systemic factors such as procurement structures or value-chain collaboration.

The aim is not to view gaps as failures, but as valuable insights that guide the next cycles of experimentation and development.

Activities

- Identify elements of the original MCLL vision that have not yet been sufficiently addressed.
- Analyse barriers that prevented certain objectives from being achieved.
- Discuss potential strategies for addressing these gaps in future intervention cycles.
- Prioritise areas where additional innovation, experimentation, or organisational change is required.
- Integrate these insights into the planning of future MCLL activities and intervention development.

Deliverables

- Vision Gap Analysis
- Prioritised List of Future Development Areas
- Recommendations for next cycles of circular intervention development

Case Example
Mannheim Medical Technology Living Labs, Germany

The Mannheim Medical Technology Living Labs (Langejürgen et al., 2024) present a large-scale, ecosystem-based approach centred around the University Hospital Mannheim in Germany. This consists of a network of interconnected innovation environments, including usability laboratories, simulated clinical settings, and integrated hospital wards. Together, these environments support different stages of innovation maturity, allowing technologies and services to move from controlled experimentation toward real-world clinical implementation.

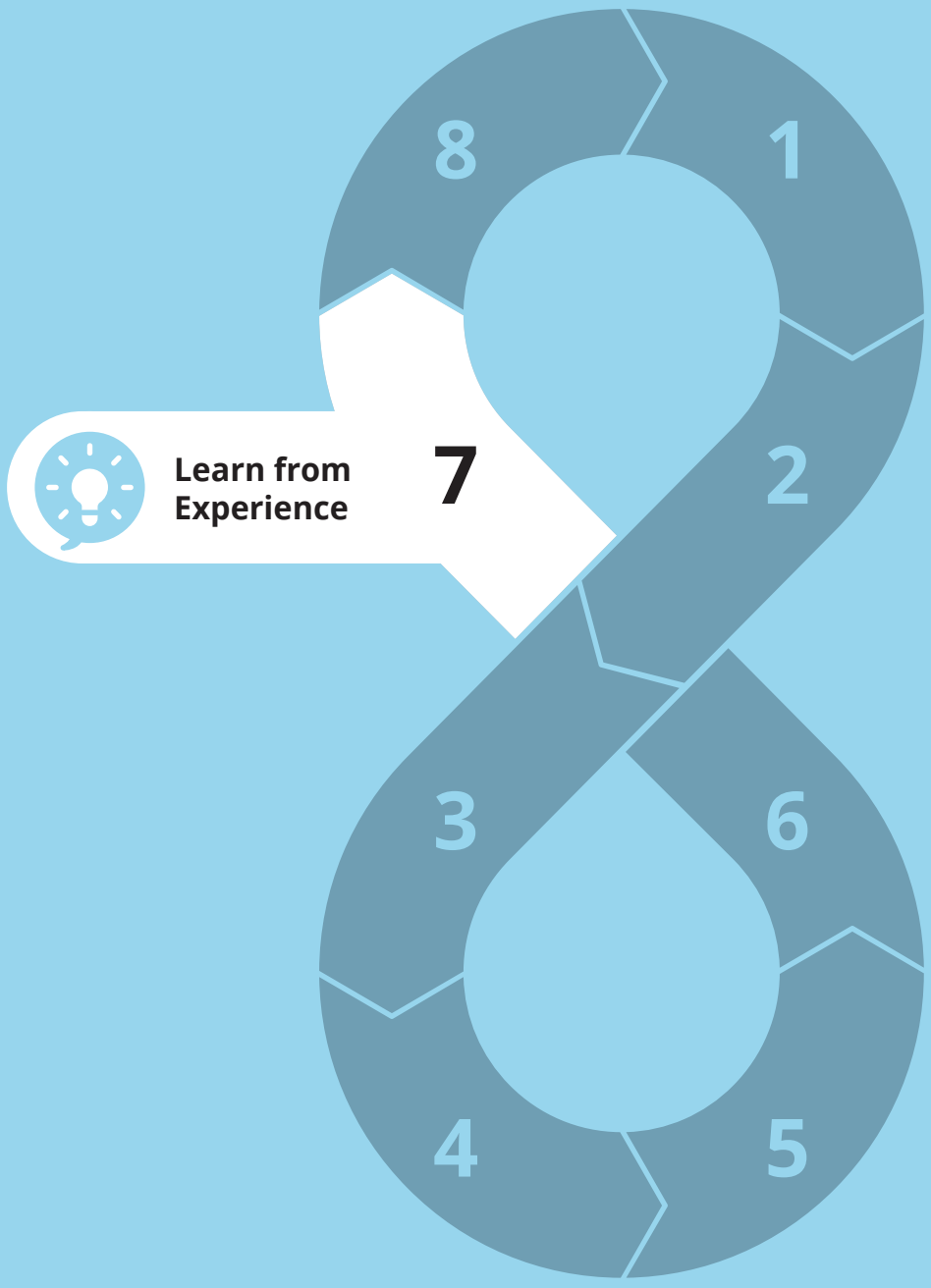
Within the ecosystem, startups, companies, clinicians, researchers, and patients collaboratively develop, test, and refine healthcare innovations, including surgical technologies, digital health applications, and process innovations such as digital patient admission systems. Strong emphasis is placed on ensuring that innovations are not developed as isolated products but as components embedded within broader healthcare processes and patient journeys.

A central characteristic of the approach is its iterative and staged development process. Innovations are first explored within controlled environments before being introduced into increasingly realistic clinical settings. Throughout these stages, continuous stakeholder involvement supports iterative refinement of innovations.

The case demonstrates how networked Living Lab infrastructures can support different innovation types and stages of development. It illustrates that embedding innovation activities within real healthcare environments improves the relevance, usability, and adoptability of solutions. At the same time, the case highlights the importance of structured coordination within the ecosystem. Finally, the study emphasizes that continuous attention to workflows and regulatory requirements can reduce implementation risks and accelerate the transition from experimentation to clinical practice.

Step 7

Learn from Experience


Learn from Experience
7
1
2
3
4
5
6
8

Introduction Step 7

This step focuses on translating the experiences and insights gained from experiments into structured learning. In many cases, after finalizing Step 6, MCLL teams may move directly into a next intervention development cycle by returning to Step 3. This may occur when promising opportunities for further improvements have been identified and rapid iteration is considered necessary. However, innovation teams may become overly focused on continuously improving a specific intervention or technology. Without broader reflection, this can result in a narrow focus that overlooks other systemic, organisational, and governance-related challenges. Therefore, Steps 7 and 8 should always be conducted, even if only in a limited or accelerated manner. This ensures that the broader systemic perspective remains central within the MCLL process.

Learning in MCLLs takes place at two complementary levels. First, stakeholders reflect on the operational outcomes and practical experiences generated through the experiments themselves. This involves identifying lessons regarding the design, feasibility, usability, and implementation of specific circular interventions. At this operational level, stakeholders learn how interventions function in real healthcare settings and how implementation strategies can be improved.

Second, stakeholders reflect on the broader collaboration processes, governance structures, and organisational implications of the MCLL as a whole. This institutional level of learning focuses on how organisations and networks coordinate innovation activities, organise collaboration, and develop new governance and innovation practices. Together, these learning processes strengthen both the development of concrete circular innovations and the long-term innovation capacity of the broader MCLL network.

In this way, Step 7 contributes not only to improving specific interventions, but also to strengthening the broader transition capacity of participating healthcare organisations and innovation ecosystems.

Key Activity 7.1: Experimental Reflection and Lessons Learned

Objective

To reflect on experimental results, stakeholder experiences, and implementation processes in order to extract practical lessons that support the further development of concrete innovations and interventions.

Description

This activity focuses on learning directly from the experiments conducted within the real-life clinical environments. Reflection takes place across three complementary dimensions:

- learning about concrete intervention performance and usability;
- learning from stakeholder experiences and collaboration;
- learning about the processes and approaches that were applied for the interventions within the MCLL environment;

Following testing, validation, and evaluation activities, stakeholders reflect not only on quantitative performance results, but also on qualitative experiences gathered during the interventions. This provides insight into how interventions functioned in clinical practice, how stakeholders interacted with the solutions, and which barriers or opportunities emerged during implementation.

The activity supports both single-loop learning, aimed at improving concrete innovations, and broader reflective learning about how the experimentation processes themselves can be strengthened in future innovation cycles. By documenting both successes and failures, the MCLL develops a shared understanding of what works, under which conditions, and why. These insights contribute to the continuous improvement of circular healthcare innovation practices.

Activities

- Conduct structured reflection sessions with clinicians, researchers, designers, patients, and industry partners involved in the experiments.
- Review intervention results based on user feedback, observational findings, operational data, and implementation experiences from the clinical setting.
- Reflect on usability, workflow integration, technical feasibility, and system-level implications of the interventions.
- Analyse stakeholder experiences, interdisciplinary collaboration dynamics, communication processes, and co-creation practices during experimentation.
- Evaluate the effectiveness of the experimental setup, testing methods, data collection approaches, and implementation strategies used.
- Identify barriers, enabling factors, unintended consequences, and opportunities for future intervention development.
- Document both successful aspects of the interventions and challenges encountered during experimentation.
- Summarize lessons learned and formulate recommendations for future experimentation and circular intervention design.

Deliverables

- Experiment Reflection Report
- Lessons Learned Overview from Interventions
- Recommendations for Improving Future Experimentation and Intervention Design
- Updated Insights for Future Intervention Development Cycles

Key Activity 7.2: Institutional Learning and Reflection

Objective

To translate insights from experiments and collaboration processes into organisational and network-level learning that strengthens the long-term innovation capacity of the MCLL and its partners.

Description

While the previous activity focuses on learning from specific experiments and interventions, this activity focuses on learning at the level of organisations, governance structures, and the broader innovation ecosystem. Through structured reflection and knowledge exchange, stakeholders examine how collaboration processes, institutional arrangements, and innovation practices functioned during the project.

This activity contributes to the institutionalisation of learning within participating organisations and networks. Partners reflect on how the existing MCLL structure supported or constrained innovation processes, how collaboration and governance arrangements can be improved, and how lessons learned can be embedded into organisational strategies, routines, and future implementation roadmaps.

Over time, these reflection processes contribute to the development of a broader learning ecosystem in which knowledge exchange, collaboration, and continuous improvement extend beyond individual projects and become integrated within healthcare innovation systems.

Activities

- Organise quarterly or bi-annual reflection sessions with all MCLL partners and relevant stakeholders.
- Discuss lessons learned regarding collaboration, governance structures, stakeholder coordination, and innovation management processes.
- Reflect on how the MCLL structure supported or constrained the development and implementation of circular interventions.
- Identify organisational barriers and enabling conditions for effective circular healthcare innovation.
- Review how knowledge exchange and collaboration occurred across organisations and disciplines.
- Document organisational, governance, and network-level insights emerging from the MCLL activities.
- Identify opportunities to strengthen future collaboration structures, innovation routines, and implementation approaches.
- Integrate lessons learned into updated innovation strategies, implementation roadmaps, and future MCLL cycles.

Deliverables

- Reflection Documents
- Organisational Learning Report
- Governance and Collaboration Improvement Recommendations
- Updated Innovation and Implementation Roadmaps

Case Example
Lecco Innovation Living Lab, Italy

Marone et al. (2020) describe the Lecco Innovation Living Lab in Italy as a multi-stakeholder healthcare innovation environment in which hospitals, companies, researchers, and public actors collaboratively developed and implemented healthcare innovations through continuous interaction and iterative learning processes. The case illustrates how Living Labs can function not only as experimentation environments, but also as infrastructures for organisational learning and stakeholder coordination within complex healthcare ecosystems.

A central insight from the study is that successful healthcare innovation depends strongly on the ability of stakeholders to continuously align expectations, reflect on collaboration processes, and adapt to emerging organisational and regulatory realities. Because different actors operate with different professional cultures, priorities, timelines, and definitions of value, structured communication and iterative feedback processes were essential for maintaining collaboration and enabling progress.

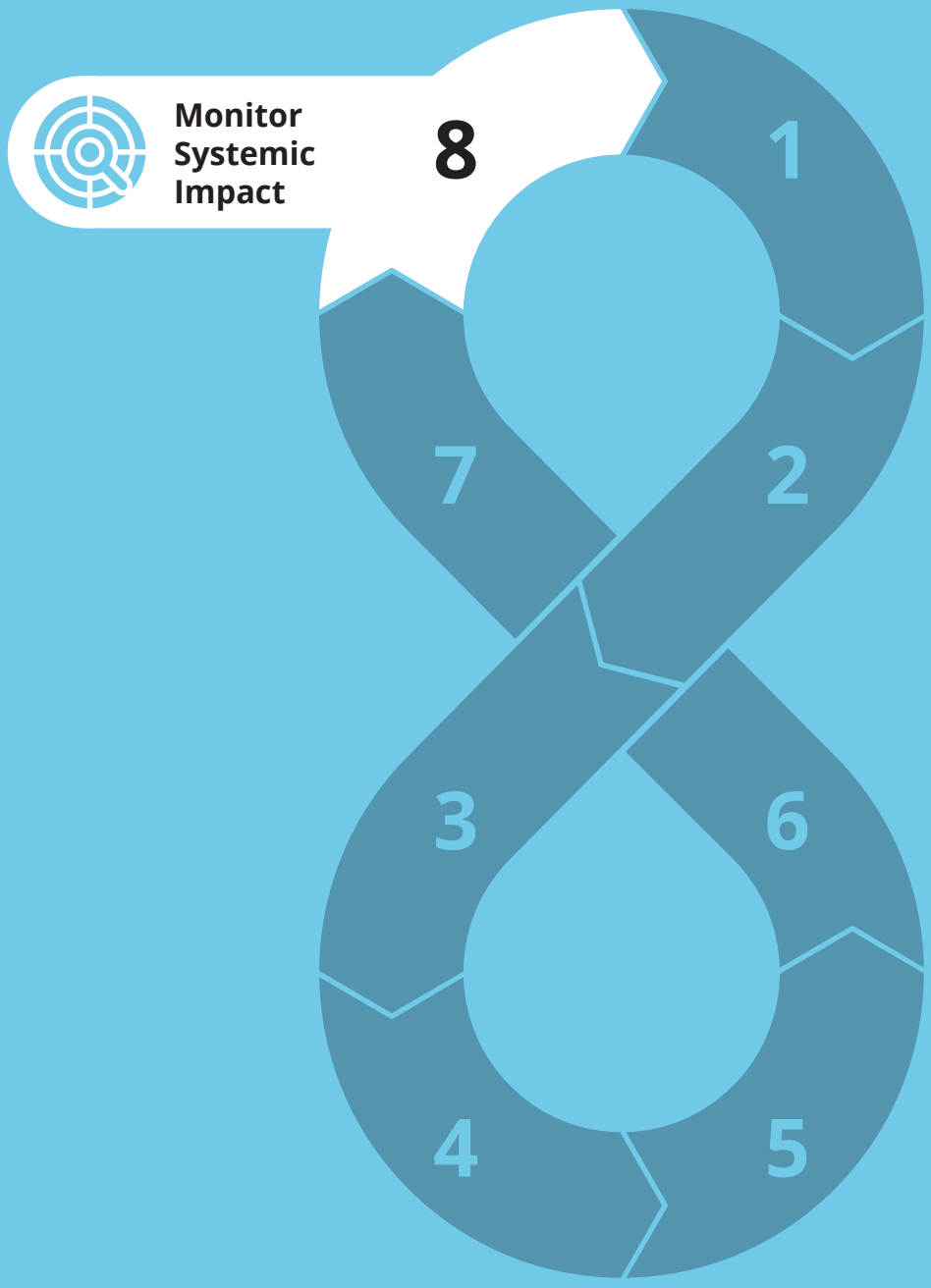
The Living Lab therefore functioned as a learning-oriented intermediary structure that supported trust-building, knowledge exchange, and collective problem-solving across the healthcare value chain. Through iterative experimentation and continuous stakeholder interaction, innovations became progressively better aligned with clinical workflows and organisational practices.

At the same time, the case highlights several challenges characteristic of Medical Living Labs, including resistance to change, regulatory complexity, competing stakeholder interests, and the difficulty of coordinating innovation activities across multiple organisations. The study emphasizes that long-term success depends not only on technological innovation itself, but also on the ability of stakeholders to institutionalize learning, adapt governance structures, and embed collaboration processes within healthcare practice.

Step 8

Monitor Systemic Impact

Monitor Systemic Impact



Introduction Step 8

Step 8 focuses on the monitoring of systemic impact of the interventions designed, and on embedding, scaling, and replicating successful circular interventions. Validated solutions are integrated into hospital policies, procurement systems, and sustainability strategies. Partnerships with industry and new departments enable replication and commercialization. Continuous monitoring ensures sustained performance and improvement. This phase turns experimental results into lasting institutional change - extending the impact of MCLLs across healthcare systems and their value chains.

Key Activity 8.1: Monitoring of Systemic Impact

Objective

To establish a continuous and structured monitoring system that evaluates the environmental, economic, operational, and social impacts of MCLL activities from the outset, ensuring that interventions deliver measurable value and inform iterative improvement.

Description

Monitoring of impact is a core component of the MCLL approach, enabling evidence-based decision-making throughout the innovation process. From the early stages, a continuous monitoring system should be implemented to track key performance dimensions, including environmental outcomes such as CO_2 emissions and waste reduction, economic and operational performance, user satisfaction, stakeholder engagement, and research output. This ongoing assessment supports transparency, accountability, and learning across stakeholders.

A mixed-method approach is helpful to capture both measurable outcomes and experiential insights. Quantitative metrics such as Life Cycle Assessment results, material recovery rates, and cost indicators, should be complemented by qualitative methods, including interviews, observations, and questionnaires. Together, these provide an understanding of the effectiveness, feasibility, and acceptance of circular interventions.

Activities

- Development of Monitoring Framework: Define key impact domains (environmental, economic, operational, social, research). Establish relevant KPIs and indicators aligned with MCLL objectives.
- Data Collection System Setup: Design and implement systems for continuous data collection from the start. Integrate monitoring into clinical workflows where possible.
- Mixed-Method Data Gathering: Conduct qualitative assessments through interviews, observations, questionnaires. Collect quantitative data based on LCA results, MFA data, waste volumes, material recovery rates, cost data, business models.
- Analysis and Interpretation: Analyse data to assess performance against defined KPIs. Identify trends, trade-offs, and unintended effects.

Deliverables

- Impact Monitoring Framework (KPIs and indicators)
- Data Collection and Measurement Plan
- Periodic Impact Assessment Reports
- Integrated Impact Dashboard (environmental, economic, social metrics)

Key Activity 8.2: Scaling, Implementation, Commercialization and Replication

Objective

Ensure that the circular healthcare innovations are scaled beyond pilot settings and embedded into the hospital systems, while exploring commercialization pathways and replication across departments or institutions.

Description

This activity ensures that circular healthcare innovations move beyond isolated pilots and become embedded within hospital systems, while also enabling broader replication and potential commercialization. This involves aligning validated solutions with institutional strategies, integrating them into procurement, clinical workflows, and sustainability policies, and supporting their roll-out across departments. By identifying suitable replication contexts and facilitating stakeholder alignment, successful interventions, such as reusable products or optimized processes, can be adapted and implemented in new clinical settings, increasing their overall impact.

In parallel, the activity explores pathways for scaling through collaboration with industry partners, including product refinement, certification, and large-scale production, as well as mechanisms such as licensing or public–private partnerships. Continuous monitoring through dashboards and performance indicators ensures that circular, clinical, and financial outcomes are maintained and improved over time.

Although many of the scaling and implementation activities may fall outside the direct responsibility and influence of the MCLL team members, it is essential to anticipate them and, where possible, play a catalytic role by enabling and supporting key stakeholders such as hospital departments and medtech industry partners to take the lead in broader implementation of promising innovations.

Activities

- **Strategic Integration**: Align validated solutions with hospital-wide procurement, clinical, and sustainability strategies. Update hospital policies and protocols to include circular interventions
- **Departmental Roll-Out**: Identify similar departments for replication (e.g., scaling lessons learned from one department to another department). Conduct stakeholder alignment and adaptation workshops in new departments.
- **Commercialization Pathways**: Collaborate with healthcare and industry partners to refine, certify, and produce validated products at scale. Secure Intellectual Property Rights where relevant and explore licensing, spin-offs, or public-private partnerships.
- **Monitoring Post-Scale Impact**: Implement dashboards and KPIs to assess ongoing circularity, clinical, and financial performance. Establish feedback loops to gather post-deployment insights and iterate design if needed.

Deliverables

- Implementation and Replication Plan
- Commercialization Brief or Partnership Agreements
- Circularity and Impact Metrics Dashboard
- Replication Case Reports

Do's and Don'ts

The eight-step MCLL Process as presented in this guidebook presents a process where insights generated through evaluation, integration, learning, and impact monitoring continuously feed back into new rounds of co-creation and experimentation. However, reality always comes in the way of a well-designed plan. This means that the actual MCLL innovation process will be much less predictable and plannable then described here. Activities will be going back and forth, steps are being skipped or can be done only partially, there will be delays, time restraints, depleted or diverted budgets, key persons leaving the team, and other practical hurdles. To support effective implementation of each step in the MCLL process, the following key success factors and practical tips highlight what to prioritise and what to avoid when navigating the complexities of circular innovation in healthcare.



Photograph by Jonathan Borba via Pexels. Used under the Pexels License.
This photograph is excluded from the Creative Commons licence applicable to the text of this book.

Key Success Factors and Problems to Avoid



Step 1 – Determine Circular Ambition

Key Success Factors

- Clear Vision
- Engaged Stakeholders
- Strong Governance

Avoid Problems

- Vague Goals
- Missing Key Partners
- Unclear Roles



Step 2 – (Re)Design MCLL

Key Success Factors

- Right Location
- Department Ownership
- Hotspot Analysis

Avoid Problems

- Convenient Sites
- Weak Embedding
- Poor Data



Step 3 – (Re)Design Circular Interventions

Key Success Factors

- Co-Creation Team
- Feasible Solutions
- User Involvement

Avoid Problems

- Technical Focus
- Too Many Ideas
- Unrealistic Plans



Step 4 – Test and Experience Interventions

Key Success Factors

- Prepared Testing
- Ethics & Safety
- Data Collection

Avoid Problems

- Rushed Testing
- Regulatory Delays
- Missing Data

Step 5 – Evaluate Interventions



Key Success Factors

- Clear Criteria
- Stakeholder Input
- Decision Points

Avoid Problems

- Biased Views
- Skipped Reflection
- Unclear Outcomes

Step 6– Integrate and Contextualise



Key Success Factors

- Align with Vision
- Identify Systemic Gaps
- Prioritise Steps

Avoid Problems

- Narrow Focus
- No Strategy Link
- Lack of Direction

Step 7 – Evaluate and Learn



Key Success Factors

- Reflect & Learn
- Share Insights
- Embed Knowledge

Avoid Problems

- Ad-Hoc Learning
- No Documentation
- Lost Lessons

Step 8 – Monitor Systemic Impact



Key Success Factors

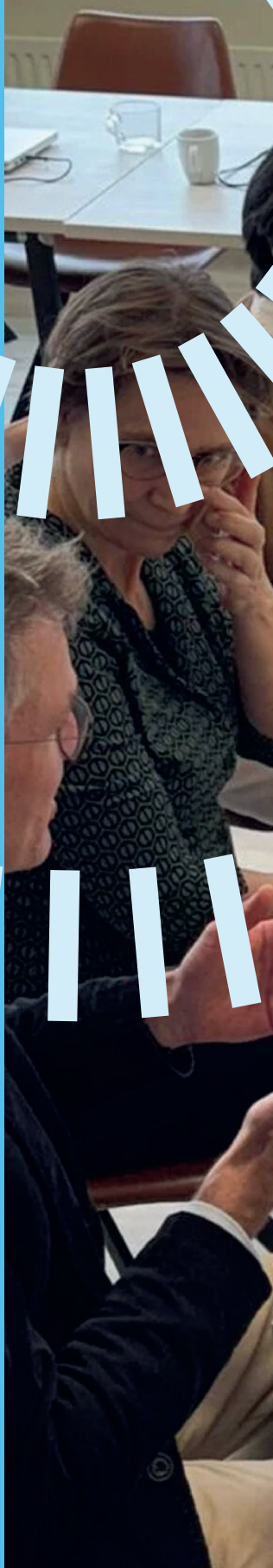
- Impact Tracking
- Scaling Plans
- Replication Support

Avoid Problems

- No Follow-Up
- No Scaling Path
- Lack of Ownership

Chapter 7

Coordinating a Medical Circular Living Lab





Photograph © Maaike van Zuilen, 2026. All rights reserved. Reproduced with permission.
This image is excluded from the Creative Commons licence applying to the text in this book.

What does it take to coordinate an MCLL?

Coordinating a Medical Circular Living Lab (MCLL) means guiding a collaborative innovation process in which stakeholders jointly explore, develop, and implement circular interventions in healthcare practice. This process is inherently iterative and takes place in a real-life environment, where ideas are continuously tested, adjusted, and refined.

An MCLL operates within a complex and highly regulated healthcare system, in which clinical processes, patient safety requirements, procurement structures, and sustainability ambitions are closely interconnected. As a result, coordination is not simply about organising activities, but about navigating this complexity and ensuring that new interventions can meaningfully connect to existing practices and constraints.

Rather than following a predefined sequence of steps, the MCLL process evolves over time. New insights may shift the direction of the process, and emerging challenges may require the involvement of additional stakeholders or expertise. This means that roles, responsibilities, and priorities are not always fixed in advance, but develop in response to the needs of the process.

In this context, coordination is less about controlling the process and more about enabling it. It involves maintaining coherence across different activities, supporting alignment between stakeholders, and creating the conditions for collaboration, experimentation, and learning to take place effectively. This requires an adaptive approach, in which the coordinator continuously responds to what is needed at a given moment to facilitate both local progress and longer-term system change.

What does an MCLL coordinator do?

The MCLL coordinator is responsible for enabling the Living Lab to function effectively and ensuring that interventions contribute to both local improvements and system-level impact. This involves organising and guiding the overall innovation process, while maintaining alignment with organisational strategies, sustainability ambitions, and regulatory frameworks.

A key responsibility is to coordinate collaboration between stakeholders, including medical and support staff, researchers, designers, industry partners, and policymakers. The coordinator ensures that all relevant actors are involved at the right moments and that collaboration initiatives lead to concrete outcomes. The coordinator also supports the development and implementation of interventions in practice. This includes the design, testing, and monitoring of solutions within the clinical environment, while safeguarding feasibility, safety, and relevance.

In addition, the coordinator connects knowledge from different domains by translating insights from research, design, and practice into actionable steps. This supports decision-making and helps ensure that interventions are grounded in both evidence and real-world applicability. Another important responsibility is to organise the collective learning processes, including evaluation and reflection. By capturing lessons learned and feeding them back into the innovation process, the MCLL coordinator promotes continuous improvement.

Finally, the coordinator facilitates the embedding and scaling of successful interventions by linking outcomes to organisational processes, procurement structures, and policy development. Together, these responsibilities require maintaining a balance between structure and flexibility, ensuring that the MCLL process remains both coherent and responsive.

What skills does an MCLL coordinator need?

Effective coordination of an MCLL depends on a combination of management skills, a practical mindset, strong communication qualities, and strategic capabilities. At the core, the coordinator needs systems thinking to understand how complex clinical processes, circularity principles, and organisational structures are interconnected. This is complemented by skills in facilitation and co-creation, enabling the design and guidance of collaborative processes involving diverse stakeholders. In addition, the coordinator must be capable of managing innovation and experimentation by overseeing iterative cycles of designing, testing, learning, and refining interventions in real-life hospital settings. Strong communication and knowledge-sharing abilities are essential to translate insights across stakeholder groups and foster a shared understanding.

Beyond these core competencies, the role requires a specific mindset and set of soft qualities. Empathy is crucial to understand the needs and constraints of healthcare professionals and other stakeholders, and to communicate in ways that resonate with them. Adaptability and resilience are needed to respond effectively to uncertainty, changing conditions, and practical challenges. Ethical awareness ensures that experimentation aligns with patient safety, data protection, and broader sustainability and circularity values. A strong reflection and learning orientation supports continuous improvement and helps cultivate a reflective working culture within the MCLL.

Strategically, the coordinator must be able to align MCLL activities with broader systemic challenges, as well as organisational and policy goals within the healthcare system. This includes effective stakeholder management to build trust, navigate different interests, and support long-term collaboration. Leadership and empowerment are also key, requiring the coordinator to take initiative while enabling others to contribute and take ownership. Finally, cross-scale thinking is important to connect local experiments to wider system change, ensuring that insights and successes extend beyond individual interventions.



Operation Room UMC Utrecht. Photograph © Redmer van Leeuwen, 2026. All rights reserved. Reproduced with permission.
This image is excluded from the Creative Commons licence applying to the text in this book.

What are the roles of an MCLL coordinator?

How an MCLL coordinator operates cannot be reduced to a fixed set of tasks; rather, it is a dynamic and responsive process that evolves over time. Depending on the phase of the Living Lab, the coordinator moves between different roles, ranging from initiating collaborations between stakeholders to facilitating co-creation processes, supporting interventions, and embedding results. By continuously shifting between these roles, the coordinator ensures that the MCLL remains aligned, inclusive, and impactful (Figure 12).

In the role of **initiator**, the coordinator identifies circular healthcare challenges, mobilises stakeholders, and lays the foundation for the MCLL. This role is especially prominent in the early phase, when the focus is on defining the challenge, aligning with sustainability goals, and building a collaborative network of partners. As the process develops, the coordinator takes on the role of **facilitator**, designing and guiding co-creation processes that support inclusive participation and foster shared understanding. This includes organising workshops, moderating discussions, and ensuring that diverse perspectives—clinical, technical, and organisational—are effectively integrated into the development of interventions.

At the same time, the coordinator acts as a **networker** by building connections across departments, organisations, stakeholders, and system levels. In this capacity, the coordinator links the MCLL to external partners, other Living Labs, and broader initiatives, thereby supporting knowledge exchange and collaboration. Closely related to this is the role of **interpreter**, in which the coordinator translates between different domains and stakeholder perspectives. This involves bridging clinical practice, sustainability goals, technical design, and ethical and regulatory requirements, ensuring that insights are both understandable and actionable.

During the experimentation phase, the coordinator takes on the role of **developer**, supporting the development, prototyping, and testing of interventions, and helping to translate ideas into practical applications within healthcare settings. Finally, in the role of **reframer**, the coordinator reflects on outcomes, extracts lessons learned

and connects results back to broader goals. This supports evaluation, continuous learning, and scaling by linking experimental outcomes to organisational strategies and system-level change.

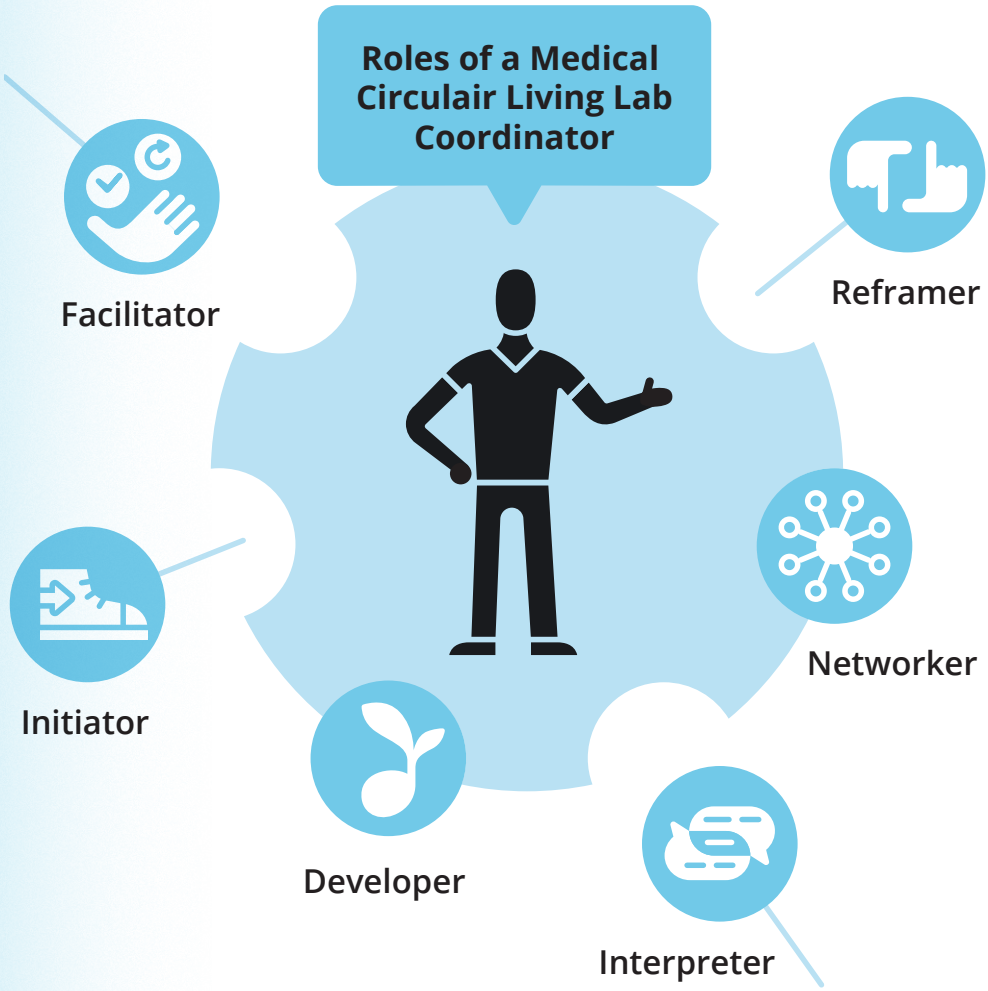


Figure 12 – Roles of the Medical Circular Living Lab Coordinator

Illustration: © Marc Kolle (2026). This illustration is not licensed under the Creative Commons licence applicable to the text of this publication.



Chapter 8
Conclusion and Glossary



Photograph © Erasmus MC Rotterdam, 2026. All rights reserved. Reproduced with permission.
This image is excluded from the Creative Commons licence applying to the text in this book.

Concluding remarks

This Medical Circular Living Lab (MCLL) guidebook provides a structured approach of how healthcare institutions can become effective real-world innovation ecosystems for circular and sustainable healthcare. By combining Medical Living Lab principles with Circular Design expertise, hospitals and other medical environments can reduce their environmental footprint, strengthen collaboration across the value chain, and lead the transition toward a circular healthcare economy.

Beyond offering a practical methodology, this guidebook positions MCLLs as a promising mechanism for systemic transformation. Rather than focusing on isolated innovations, MCLLs enable stakeholders to collaboratively work on different systemic levels of a hospital healthcare environment. This includes clinical processes, procurement models, product lifecycles, and organisational practices. By working in real-world environments, MCLLs aim to bridge the gap between experimentation and implementation, ensuring that innovations are both relevant and scalable.

A key assumption throughout this guidebook is that circularity in healthcare requires a shift from linear problem-solving toward systems thinking. Environmental impact, clinical performance, and economic feasibility are interconnected, and must therefore be addressed in an integrated way. MCLLs aim to facilitate this by creating a shared space where stakeholders can jointly analyse challenges, develop interventions, and iteratively refine them based on real-world feedback.

The guidebook emphasizes the importance of co-creation as a key element of the systemic innovation process. Engaging clinicians, designers, researchers, industry partners, and managers ensures that solutions are grounded in practice, broadly supported, and aligned both with all relevant requirements from within the healthcare system, as well as with long-term circularity and sustainability goals.

Ultimately, MCLLs can function as learning environments that aim to support continuous innovation and improvement. Through iterative cycles of design, testing, and evaluation, they enable organizations to respond to emerging circular challenges and support the transformation towards a sustainable healthcare system.

Glossary

The concepts used in this guidebook originate from different academic and professional domains, including Living Lab research, circular economy, systems thinking, design research, healthcare innovation, and implementation practice. Many of these concepts have been defined and interpreted in different ways in the literature.

The definitions presented here do not aim to provide definitive or universally accepted meanings. Instead, they reflect how the authors interpret and apply these concepts within the context of Medical Circular Living Labs. In several cases, existing definitions have been adapted or combined to better fit the specific context of circular innovation in healthcare. The purpose of this glossary is therefore not to standardise terminology beyond this publication, but to support a shared understanding among stakeholders working with the MCLL approach.

Living Lab Concepts

Term	Definition
Circular Living Lab	A Living Lab focused on developing and testing solutions that support circular economy objectives.
Co-creation	The active involvement of multiple stakeholders in jointly exploring challenges, developing solutions, and evaluating outcomes.
Living Lab	A collaborative innovation environment where stakeholders develop, test, and refine solutions in real-life settings.
Medical Circular Living Lab	A Living Lab that combines healthcare innovation and circular economy goals to develop, test, and implement circular solutions in clinical practice.
Medical Living Lab	A Living Lab situated in healthcare settings and governed by clinical, ethical, and regulatory requirements.
Stakeholder	An individual or organisation that influences, participates in, or is affected by a Medical Circular Living Lab and its outcomes.

Circular Economy Concepts

Term	Definition
Circular Economy	An economic system that aims to minimise waste and resource use by retaining the value of products, materials, and resources for as long as possible.
Circular Intervention	A product, process, service, or system change intended to improve circularity and reduce environmental impact within a healthcare context.
Circular Procurement	The purchasing of products and services based not only on price and performance, but also on their potential to retain value, minimise waste, and support circular economy objectives.
Circularity	The extent to which products, materials, and systems retain their value through strategies such as reduction, reuse, repair, refurbishment, remanufacturing, and recycling.
R-Ladder	A hierarchy of circular strategies (R0–R9) that ranks interventions according to their potential to retain value and reduce resource consumption.
Value Hill	A framework that visualises how value is created, maintained, and recovered throughout the lifecycle of products, materials, and resources.

Systems and Innovation Concepts

Term	Definition
Governance	The structures, roles, responsibilities, and decision-making processes that guide the operation and development of an initiative or organisation.
Iteration	The repeated cycle of designing, testing, evaluating, and refining an intervention based on new insights and feedback.
Scaling	The process of expanding, adapting, or embedding a successful intervention so that it creates impact beyond its original context.
Systemic Change	A transformation that affects multiple interconnected elements of a system, such as structures, processes, behaviours, relationships, and rules, rather than a single isolated component.
Systemic Design	A design approach that combines systems thinking and design methods to develop interventions that address challenges across interconnected parts of a system.
Systems Thinking	An approach that focuses on understanding relationships, interactions, and dependencies between elements of a system rather than considering them in isolation.

Healthcare Concepts

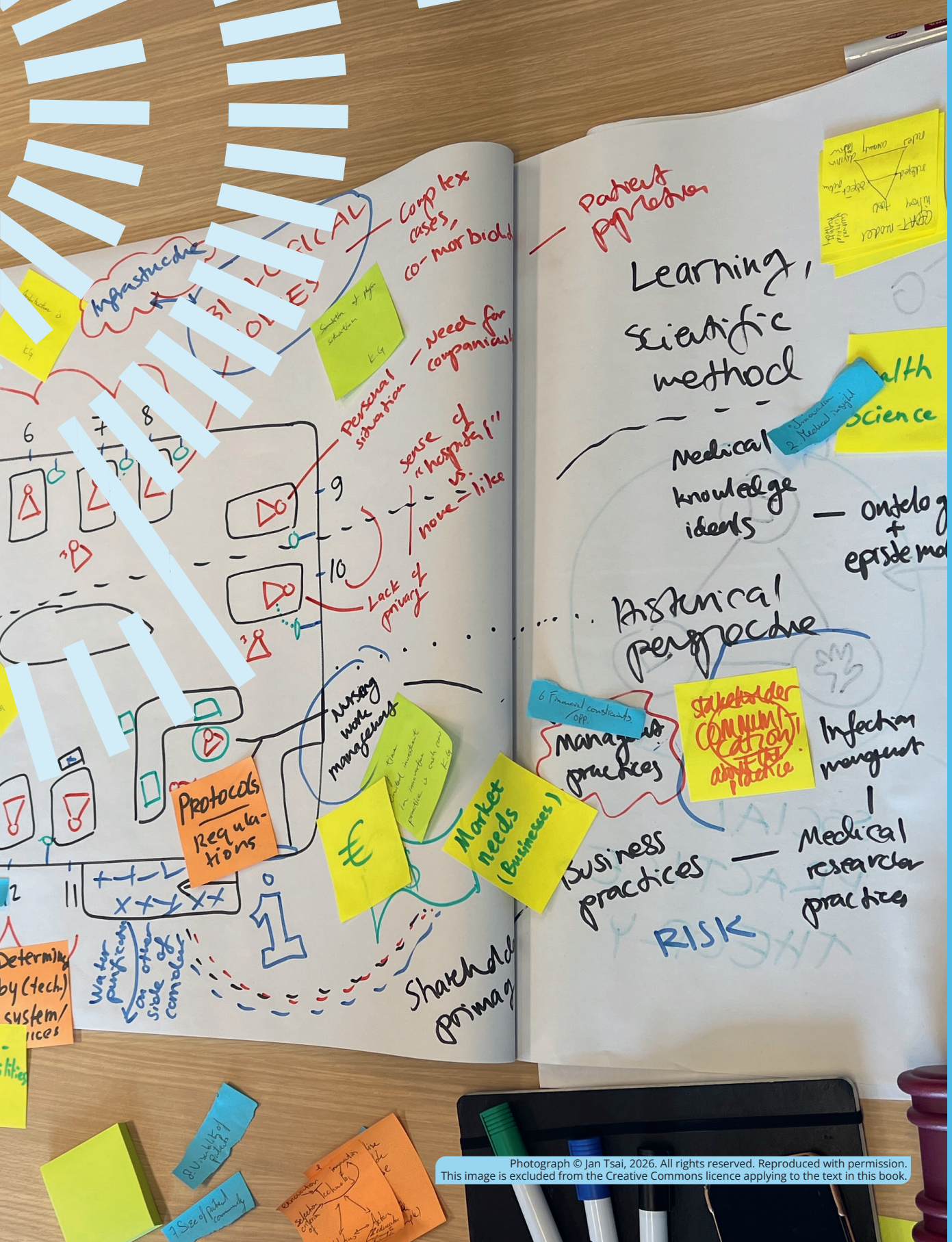
Term	Definition
Clinical Validation	The process of demonstrating that an intervention performs effectively, safely, and as intended within a clinical context.
Clinical Workflow	The sequence of tasks, activities, and decisions through which healthcare professionals deliver patient care.
Infection Prevention	The policies, procedures, and practices used to reduce the risk of healthcare-associated infections and ensure safe patient care.
Medical Consumable	A medical product or material intended for use during healthcare delivery that is consumed, discarded, or requires replacement after use.
Patient Safety	The prevention of avoidable harm to patients during the delivery of healthcare services.
Regulatory Compliance	The adherence of products, processes, and organisations to applicable laws, regulations, standards, and certification requirements.
Reprocessing	The process of cleaning, disinfecting, sterilising, inspecting, and preparing a medical product for safe reuse.

Multilevel Framework Concepts

Term	Definition
Department-Level Innovation System	The local organisational environment within a hospital department where healthcare professionals and supporting functions develop, test, and implement innovations in daily practice.
Healthcare Ecosystem	The broader network of organisations, policies, regulations, funding mechanisms, and value-chain actors that influence healthcare innovation and delivery.
Hospital Ecosystem	The network of departments, functions, professionals, processes, and resources within a hospital that collectively enable healthcare delivery and innovation.
Multi-Level Framework	A conceptual model that connects three levels of healthcare innovation: the (inter)national healthcare and hospital ecosystem, the department-level innovation system, and real-life clinical settings. The framework helps relate local experiments and interventions to organisational and system-level change.
Real-Life Clinical Setting	An actual healthcare environment in which patient care is delivered and innovations can be tested under real operational, clinical, and organisational conditions.



References



Photograph © Jan Tsai, 2026. All rights reserved. Reproduced with permission.
This image is excluded from the Creative Commons licence applying to the text in this book.

- Achterberg, E., Hinfelaar, J., & Bocken, N. (2016). *Master circular business models with the Value Hill* [White paper]. Circle Economy.
- Buck, H. P. (2025). *Circular care: Improving the environmental impact of infusion bags in hospitals* [Master's thesis, Delft University of Technology]. TU Delft Repository. https://resolver.tudelft.nl/uuid:6c8870f9-1316-478b-9a9d-8421b9473243
- Dijkstra, A. M., & Joore, P. (2025). *The urban living lab way of working handbook*. Amsterdam Institute for Advanced Metropolitan Solutions. https://resolver.tudelft.nl/uuid:cccb188d-09d7-4480-b963-4736ab176b5a
- Fotis, T., Kioskli, K., Sundaralingam, A., Fasihi, A., & Mouratidis, H. (2023). Co-creation in a digital health living lab: A case study. *Frontiers in Public Health, 10*, Article 892930. https://doi.org/10.3389/fpubh.2022.892930
- Hakkarainen, L., & Hyysalo, S. (2013). How do we keep the living laboratory alive? Learning and conflicts in living lab collaboration. *Technology Innovation Management Review, 3*(12), 16–22. https://doi.org/10.22215/timreview/749
- Hanemaaijer, A., Kishna, M., Koch, J., Lucas, P., Rood, T., Schotten, K., & van Sluisveld, M. (2023). *Integrale circulaire economie rapportage 2023* [Integral circular economy report 2023] (PBL-publicatienummer 4882). Planbureau voor de Leefomgeving. https://www.pbl.nl/publicaties/integrale-circulaire-economie-rapportage-2023
- Hannula, J. (2021). *Piloting a new service in a healthcare living lab environment—Case: Medified* [Master's thesis, Laurea University of Applied Sciences]. Theseus. https://urn.fi/URN:NBN:fi:amk-2021121890017
- Huijben, J., van Raaij, E., Wagelmans, A., Piscicelli, L., Shen, W.-S., van Vliet, B., Gommers, D., Tibboel, D., Bakker, E., Dekkers, F., van Leeuwen, R., Diehl, J. C., & Hunfeld, N. (2025). Accelerating the transition from a linear to a circular healthcare sector: ESCH-R: Study design and methodology. *Frontiers in Public Health, 13*, Article 1542187. https://doi.org/10.3389/fpubh.2025.1542187
- Klasen, J., Rijcks, S., Gommers, D., Diehl, J. C., & Hunfeld, N. (2025). Circular material flow of medication in the intensive care unit. *Critical Care, 29*(1), Article 205. https://doi.org/10.1186/s13054-025-05434-3
- Kuiper, E. F. (2025). *Sensing a sustainable future: A holistic approach to pulse oximetery product and system design for sustainable medical device adoption* [Master's thesis, Delft University of Technology]. TU Delft Repository. https://resolver.tudelft.nl/uuid:3713f4cb-e408-4e1e-bb50-a40e565d32c6

Langejürgen, J., Maier, P., Hennes, H.-J., Fox, K., Eichner, S., Winter, L. K., Krause, H., Gustedt, A., Moorthy, P., Langhals, M., & Siegel, F. (2024). *Living labs for medical technology: The Mannheim model* [White paper]. Universitätsbibliothek Heidelberg. https://doi.org/10.11588/heidok.00036380

Marone, L., Onofrio, R., & Masella, C. (2020). The Italian case of Lecco Innovation Living Lab: Stakeholders' needs and activities to contribute to the technological innovation process in healthcare. *Sustainability, 12*(24), Article 10266. https://doi.org/10.3390/su122410266

Merino-Barbancho, B., Abril Jiménez, P., Mallo, I., Lombroni, I., Cea, G., López Nebreda, C., Cabrera, M. F., Fico, G., & Arredondo, M. T. (2023). Innovation through the Quintuple Helix in living labs: Lessons learned for a transformation from lab to ecosystem. *Frontiers in Public Health, 11*, Article 1176598. https://doi.org/10.3389/fpubh.2023.1176598

Potting, J., Hekkert, M. P., Worrell, E., & Hanemaaijer, A. (2017). *Circular economy: Measuring innovation in the product chain* (PBL Publication No. 2544). PBL Netherlands Environmental Assessment Agency. https://www.pbl.nl/downloads/pbl-2016-circular-economy-measuring-innovation-in-product-chains-2544.pdf

Puerari, E., de Koning, J. I. J. C., von Wirth, T., Karré, P. M., Mulder, I., & Loorbach, D. (2018). Co-creation dynamics in urban living labs. *Sustainability, 10*(6), Article 1893. https://doi.org/10.3390/su10061893

Santonen, T., Petronikolou, V., Petsani, D., Dimitriadis, S. K., Bamidis, P. D., & Konstantinidis, E. I. (2024). Towards living lab value proposition: Living lab experts' perceptions of living lab value. *Journal of Innovation Management, 12*(3), 251–275. https://doi.org/10.24840/2183-0606_012.003_0011

Scholl, C., de Kraker, J., & Dijk, M. (2022). Enhancing the contribution of urban living labs to sustainability transformations: Towards a meta-lab approach. *Urban Transformations, 4*, Article 7. https://doi.org/10.1186/s42854-022-00038-4

Schuurman, D., De Marez, L., & Ballon, P. (2016). The impact of living lab methodology on open innovation contributions and outcomes. *Technology Innovation Management Review, 6*(1), 7–16. https://doi.org/10.22215/timreview/956

Smulders, J.M. (2026). *Design for a reusable bicarbonate cartridge: A circular solution for hemodialysis* [Master's thesis, Delft University of Technology]. TU Delft Repository. https://resolver.tudelft.nl/uuid:1e12b9ad-23d5-4ebc-b4e5-963335cdb2ab

Steenmeijer, M. A., Pieters, L. I., Warmenhoven, N., Huiberts, E. H. W., Stoelinga, M., Zijp, M. C., van Zelm, R., & Waaijers-van der Loop, S. L. (2022). *Het effect van de Nederlandse zorg op het milieu: Methode voor milieuvoetafdruk en voorbeelden voor een goede zorgomgeving* [The Impact of the Dutch Healthcare System on the Environment: Methodology for Calculating the Environmental Footprint and Examples of a Good Healthcare Environment] (RIVM Report No. 2022-0127). Rijksinstituut voor Volksgezondheid en Milieu. https://doi.org/10.21945/RIVM-2022-0127

Tercanli, H., & Jongbloed, B. (2022). A systematic review of the literature on living labs in higher education institutions: Potentials and constraints. *Sustainability, 14*(19), Article 12234. https://doi.org/10.3390/su141912234

Turk, E., Wontor, V., Yoshida, S., Dugstad, J. H., Julius, P., Hannibal, M., Quintana, Y., & Srivastava, G. (2025). Design thinking and co-creation in integrated care. In V. Amelung, V. Stein, E. Suter, N. Goodwin, R. Balicer, & A.-S. Beese (Eds.), *Handbook of integrated care* (pp. 1–26). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-25376-8_103-1

van der Wee, M. L., Tassone, V. C., Wals, A. E. J., & Troxler, P. (2024). Characteristics and challenges of teaching and learning in sustainability-oriented living labs within higher education: A literature review. *International Journal of Sustainability in Higher Education, 25*(9), 255–277. https://doi.org/10.1108/IJSHE-10-2023-0465

van Geenhuizen, M., & Guldemond, N. (2018). Living labs in healthcare innovation: Critical factors and potential roles of city governments. In M. van Geenhuizen, J. A. Holbrook, & M. Taheri (Eds.), *Cities and sustainable technology transitions: Leadership, innovation and adoption* (pp. 318–338). Edward Elgar Publishing. https://doi.org/10.4337/9781783476770.00026

van Hulst, F., Strietman, W. J., Gileva, E., Shivarov, A., Vlachogianni, T., van Leeuwen, J., & Hendriksen, A. (2025). *Report of the second living lab: Scenarios for reducing PFAS emissions from medical applications*. SOS-ZEROPOL2030. https://soszeropol2030.eu/wp-content/uploads/2025/06/Report-of-the-Living-Lab-on-PFAS-in-medical-applications-Round-II-March-2025.pdf

Verhoef, L. A., Bossert, M., Newman, J., Ferraz, F., Robinson, Z. P., Agarwala, Y., Wolff, P. J., Jiranek, P., & Hellinga, C. (2020). Towards a learning system for university campuses as living labs for sustainability. In W. Leal Filho, A. Lange Salvia, R. W. Pretorius, L. Londero Brandli, E. Manolas, F. Alves, U. Azeiteiro, J. Rogers, C. Shiel, & A. Do Paco (Eds.), *Universities as living labs for sustainable development: Supporting the implementation of the Sustainable Development Goals* (pp. 135–149). Springer. https://doi.org/10.1007/978-3-030-15604-6_9

von Wirth, T., Fuenfschilling, L., Frantzeskaki, N., & Coenen, L. (2019). Impacts of urban living labs on sustainability transitions: Mechanisms and strategies for systemic change through experimentation. *European Planning Studies, 27*(2), 229–257. https://doi.org/10.1080/09654313.2018.1504895

List of Figures

All figures listed below are illustrations © Marc Kolle, 2026. These illustrations are not licensed under the Creative Commons licence applicable to the text of this publication.

- Figure 1. Mutually Related Aspects of the Medical Circular Challenge — p. 21
- Figure 2. Medical, Circular, and Medical Circular Living Labs — p. 25
- Figure 3. Value Hill and R-Ladder: Adding and Retaining Value — p. 29
- Figure 4. Selecting an Appropriate Innovation Approach — p. 39
- Figure 5. Medical Circular Living Labs: Multilevel Framework — pp. 60–61
- Figure 6. Healthcare and Hospital Ecosystem — p. 63
- Figure 7. Co-Creation Lab and Clinical Living Labs — p. 66
- Figure 8. Multilevel Framework — p. 67
- Figure 9. Mutual Interaction Between System Levels — p. 75
- Figure 10. Medical Circular Living Lab Process combined with Multilevel Framework — p. 78
- Figure 11. Medical Circular Living Lab Process — p. 79
- Figure 12. Roles of the Medical Circular Living Lab Coordinator — p. 147

Photograph Credits

Unless otherwise indicated, the photographs and illustrations listed below are excluded from the Creative Commons licence applicable to the text of this publication. Photographs marked © are all rights reserved and reproduced with permission.

- Cover: Photograph © Rogier Bos, 2026.
- p. 5: Photograph © Arie Kievit, 2026.
- p. 9: Photograph by Jonathan Borba, via Pexels. Used under the Pexels License. https://www.pexels.com/photo/surgical-instruments-on-sterile-blue-drape-28727572/
- p. 13: Photograph © Erasmus MC Rotterdam, 2026.
- p. 19: Photograph © Marcel van den Bergh, 2026.
- p. 32 (top): Photograph © Jan Geerling, 2016. Source: Wikimedia Commons. Licensed under CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:1604_Erasmus_MC,_Rotterdam_014.jpg
- p. 32 (bottom): Photograph © Sneeuwvlakte, 2025. Source: Wikimedia Commons. Licensed under CC BY-SA 4.0. https://commons.wikimedia.org/wiki/File:UMC_Utrecht_(2025).jpg
- p. 35: Photograph © Jan-Carel Diehl, 2026.
- p. 40: Photograph © Fiene Kuiper, 2026.
- p. 43: Photograph © Maaike van Zuilen, 2026.
- p. 57: Photograph © Erasmus MC Rotterdam, 2026.
- p. 68: Photograph © Josje Smulders, 2026.
- p. 71: Photograph © Jan Tsai, 2026.
- p. 73: Photograph © Fiene Kuiper, 2026.
- p. 86: Photograph © Han Buck, 2026.
- p. 100: Photograph © Rogier Bos, 2026.
- p. 137: Photograph by Jonathan Borba, via Pexels. Used under the Pexels License. https://www.pexels.com/photo/doctors-in-surgery-room-13697924/
- p. 141: Photograph © Maaike van Zuilen, 2026.
- p. 145: Operating Room, UMC Utrecht. Photograph © Redmer van Leeuwen, 2026.
- p. 149: Photograph © Erasmus MC Rotterdam, 2026.
- p. 157: Photograph © Jan Tsai, 2026.

How can healthcare become more circular without compromising patient safety, clinical quality, or efficiency?

The *Medical Circular Living Labs Guidebook* offers a practical framework for turning circular ambitions into action. It shows how hospitals and their partners can create real-world innovation environments in which healthcare professionals, researchers, designers, suppliers, and policymakers, work together to develop, test, and improve circular solutions.

Developed as part of the ESCH-R project—*Evidence-based Strategies to create Circular Hospitals*—the guidebook builds on the knowledge and practical experience of a multidisciplinary research consortium working to advance circular healthcare.

Through an eight-step approach, the guidebook supports teams in defining their ambitions, establishing a Medical Circular Living Lab, co-creating and evaluating interventions, embedding lessons within the wider organisation, and working towards lasting systemic impact. Real-world cases demonstrate how these principles can be applied to medical products, material flows, clinical practices, and healthcare systems.

By combining circular design, systems thinking, experimentation, and collaborative learning, this guidebook offers both practical direction and strategic insight. It is a valuable resource for anyone working towards circular and sustainable healthcare—one experiment, one partnership, and one systemic change at a time.



TU Delft | OPEN Publishing