

The future of software maintenance and evolution

Shaping an ecosystem

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Abbreviations

Abbreviation	Meaning
AI	Artificial Intelligence
CTO	Chief Technology Officer
CWI	Centrum Wiskunde & Informatica
EU	European Union
IT	Information Technology
KPI	Key Performance Indicator
LLM	Large Language Model
R&D	Research and Development
ROI	Return On Investment
SIG	Special Interest Group
SMEvo	Software Maintenance and Evolution
TNO-ESI	Embedded Systems Innovation by TNO
TUD	Delft University of Technology
TRL	Technology Readiness Level
TU/e	Eindhoven University of Technology

Summary

This report examines the challenge of strengthening and formalizing a Software Maintenance and Evolution (SMEvo) ecosystem for the Dutch high-tech industry. Maintenance and evolution of long-lived, software-intensive systems account for a large part, estimated between 75% and 90%, of software lifecycle costs. They are frequently complicated by growing risks stemming from legacy technologies, technical debt, knowledge loss, and architectural erosion. These issues slow down innovation, increase operational risk, and threaten competitiveness.

To address these challenges, TNO-ESI initiated a knowledge development project to explore the feasibility and value of a collaborative SMEvo ecosystem for the Dutch high-tech industry. This study was guided by specific research questions to ensure a systematic exploration of organizational, human, and technical dimensions of the ecosystem establishment. Three thematic workshops, focusing on those dimensions, were organized with stakeholders from industry, academia, and IT service providers, enabling a multi-perspective analysis of the challenges. The list of stakeholders is mentioned in the acknowledgements section.

Findings indicate that:

- The viability of a SMEvo ecosystem depends on establishing collaborative governance, clearly defining the mission of the ecosystem, and clarifying the roles and responsibilities of the parties within the ecosystem.
- Stable funding is essential for supporting research, tools development, and innovation transfer between academia and industry. Conversely, securing stable funding requires robust evidence of return on investment and the formulation of compelling business cases that demonstrate both technical and business value.
- Internal competition requires structured trust-building measures, conflict-resolution mechanisms, and shared terminology. Those elements facilitate cooperation while still allowing for differentiation and competition.
- The ecosystem should support competency development and career paths creation, and establish new professional profiles. These elements are fundamental for enabling the industry to recognize the challenges of SMEvo and to apply effective solutions on a large scale.
- On the technical side, the current landscape of tools, such as Rascal, Renaissance, R.E.B.O.R.N. (built around Renaissance), and Spoofox, is fragmented. Stakeholders agreed on an interoperability-first strategy as the most pragmatic step towards a shared platform, enabling incremental progress while preserving tool diversity.

Five transition areas were identified: self-organization, knowledge, tools, funding, and education. These transition areas serve as the basis for a phased master plan to build the SMEvo ecosystem. The plan begins with foundational activities, such as positioning tools, clarifying the ownership of these tools, defining a shared vision, and outlining the value of cooperation. Those foundational activities lead to a decision point on participation. Subsequent steps include establishing governance structures, designing the knowledge base, and approving and launching the ecosystem-building roadmap. A mature SMEvo ecosystem is expected to reduce SMEvo costs and accelerate innovation through shared methods and tools, and strengthen the global competitiveness of the Dutch high-tech sector.

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We gratefully acknowledge the contributions of all participants in the workshops. Their insights and engagement were instrumental in shaping the findings and recommendations of this report.

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1 Introduction

The Dutch high-tech industry relies on software-intensive systems to drive innovation, productivity, and global competitiveness. However, these systems face ever-increasing challenges to maintainability and viability due to aging codebases, rising maintenance costs, and rapidly evolving technological demands.

Software Maintenance, defined as the modification of a software product to correct faults, improve performance, or adapt it to a changed environment, dominates the software lifecycle costs and is estimated to be **75% to 90%** of the total software expenditure [1], [2], especially for long-lived systems where maintenance spans many years.

In the Netherlands, for a codebase of 10 million lines of code¹, this translates to a COCOMO II estimate of approximately €40 million per year, as calculated in Annex: Maintenance Costs. The scale of effects of poor software quality extends beyond national borders. In 2022, poor software quality, including the costs of failures, fixes, and maintenance of legacy systems, was estimated to cost U.S. organizations \$2.41 trillion [3]. The cost to fix technical debt alone was estimated at \$1.52 trillion [3].

Recognizing the importance of this challenge, the Software Maintenance and Evolution (SMEvo) community, in which TNO-ESI is active, has expressed a strong desire to align efforts and build a shared ecosystem of methods, tools, and expertise. This collective ambition was clearly articulated during the Special Interest Group (SIG) meeting in December 2024, where stakeholders from industry and academia emphasized the importance of sustained collaboration and knowledge exchange to prevent fragmentation. Dutch institutions, such as TNO-ESI, CWI, TU/e, and TU Delft, have already made significant contributions to the SMEvo domain and continue to shape the related research and innovation agenda in the Netherlands. Nevertheless, the proliferation of tools, including Rascal, Renaissance, R.E.B.O.R.N. (built around Renaissance), and Spoofax, has led to confusion and inefficiencies. Professionals often struggle to choose the right tools and are unable to reuse artefacts across platforms. In a talent-scarce environment, consolidating efforts and simplifying the tooling landscape could offer greater value than maintaining the current level of fragmentation.

TNO-ESI can serve a pivotal role in this ecosystem, with a mission to translate research results into industrial impact and ensure that academic investigations align with the industrial needs of software engineering.

This report documents the execution and outcomes of a TNO knowledge-development project with a twofold objective: (1) to develop knowledge on the opportunities and challenges of strengthening and formalizing an SMEvo ecosystem for the Dutch high-tech industry, and (2) to create a Master Plan that outlines how this SMEvo ecosystem can be collaboratively initiated and managed.

¹ Software-intensive systems typically span tens of millions of lines of code in domains such as image-guided therapy platforms, semiconductor lithography equipment, and avionics. In automotive systems, the scale rises to hundreds of millions, while internet-scale platforms can reach billions of lines of code.

To achieve this twofold objective, three workshops were organized with stakeholders from industry, academia, and IT service providers. These workshops led to the identification of actions across five key transition areas, which together form the basis of the Roadmap and Master Plan presented in this report.

The strengthening and formalization of this SMEvo ecosystem aligns with one of TNO-ESI's strategic goals: to enhance the industrial applicability of research by connecting academic developments to real-world industry needs. This is achieved by integrating methods and tools that enable the Dutch high-tech sector to effectively and efficiently manage the increasing complexity of its systems and organizations.

While this report focuses on the outcomes of this specific TNO knowledge development project and the resulting Master Plan, it also contributes to outlining a broader, long-term vision: establish a collaborative SMEvo ecosystem that:

- provides a long-term solution for maintaining and evolving complex software systems through shared capabilities, tools, competencies, and business models;
- facilitates structured collaboration between academic and industrial partners across domains;
- generates lasting economic and strategic value for all stakeholders.

1.1 Research questions

This study was guided by specific research questions structured around three perspectives: organizational, human, and technical. Here are the research questions:

1. **Organizational Perspective:**
 - o How can conflicting business models be navigated in the context of SMEvo?
 - o What strategies can be employed to create compelling business value and cases for SMEvo?
 - o What are the best practices for ensuring stable funding for research and the maintenance of shared tools and knowledge in a SMEvo ecosystem?
2. **Human Perspective:**
 - o How can effective communication and cooperation be fostered while balancing competition among stakeholders in a SMEvo ecosystem?
 - o How can new competency profiles be developed to maintain and evolve software over the next 5 to 10 years?
 - o What competencies and roles are necessary to sustain the ecosystem for SMEvo?
3. **Technical Perspective:**
 - o How can we understand, compare, and reason about diverse technical solutions in the context of SMEvo?
 - o What are the most appropriate platforms for cooperation in SMEvo?
 - o How can the transfer of innovation between academia and industry be streamlined in the context of SMEvo?

1.2 Research method / Way of working

This study employed a qualitative, participatory, and multi-perspective research approach that incorporated structured dialogue to co-create knowledge and strategy, thereby establishing a

shared foundation for long-term collaboration. The methodology centered on three thematic workshops, each dedicated to a core perspective (organizational, human, and technical), and was complemented by structured preparation and consolidation activities led by TNO-ESI in collaboration with stakeholder representatives.

Preparation (by TNO-ESI)

- **Stakeholder Mapping:** Identified and engaged a diverse set of ecosystem actors.
- **Workshop Design:** Each workshop was designed to explore one of the three perspectives, with tailored objectives and facilitation strategies.
- **Pre-Engagement Activities:** Background research and stakeholder consultations were conducted to inform the workshop content and ensure relevance.

Workshops (by all participants)

Each of the three workshops followed a structured three-step format to guide participants through a reflective and forward-looking process:

- **Clarifying the Current Situation:** Participants identified existing challenges, gaps, and dynamics within the ecosystem from the perspective in focus.
- **Envisioning the Future:** Participants co-created a shared vision of what a well-functioning, future-ready ecosystem would look like.
- **Defining Actions:** Actions were proposed to bridge the gap between the current state and the envisioned future, with the understanding that these actions will require further refinement as the ecosystem evolves.

The workshops were organized as follows, combining facilitated discussions, collaborative exercises, and synthesis activities to ensure both depth and cross-stakeholder understanding:

- **Workshop 1 – Organizational Perspective:** using stakeholder mapping, we discussed the ecosystem parties' values and pain points.
- **Workshop 2 – Human Perspective:** through role playing, empathy mapping, and joint reflection, we explored stakeholder tensions, clarified role definition, and addressed communication and competence development.
- **Workshop 3 – Technical Perspective:** we mapped the current tool landscape, analyzed interoperability opportunities, and defined scenarios for shared tools and knowledge assets to facilitate innovation transfer.

Consolidation (by TNO-ESI)

- **Synthesis of Findings:** Workshop outputs were analyzed and summarized.
- **Validation and Feedback:** Preliminary insights were shared with the participants for review and refinement.
- **Integration into the Master Plan:** The final step involved consolidating all findings into a strategic roadmap for ecosystem strengthening and formalization.
- In total, 11 organizations and 27 participants contributed to the workshops, ensuring representation from industry, academia, and IT service providers.

1.3 Report structure

This report is organized as follows:

- **Chapter 1: Introduction**
Introduces the motivation behind the project, the SMEvo challenges faced by the Dutch high-tech industry, the rationale for ecosystem development, the three perspectives, and the research questions and research method used.
- **Chapter 2: State of the Art and Practice**
Presents the general context, current research trends, and industrial practices in SMEvo, with a focus on contributions from Dutch institutions involved in the workshops. It also introduces ecosystem thinking as a strategy for collaboration.

- **Chapter 3: Learnings on the Research Questions**
Synthesizes insights from literature and workshops related to the research questions explored across the three perspectives (organizational, human, and technical) relevant to the creation of a SMEvo ecosystem.
- **Chapter 4: Transitions**
Identifies five key transition areas (self-organization, knowledge, tools, funding, and education) and outlines the necessary actions to transition from the current situation to the envisioned ecosystem.
- **Chapter 5: Master Plan**
Introduces a phased plan to guide ecosystem development, starting with foundational actions and stakeholder alignment (including a decision to participate), and leading to a roadmap for future implementation.
- **Chapter 6: Conclusion**
Summarizes key findings and highlights next steps for stakeholders to advance the SMEvo ecosystem.

2 State of the art and practice

International standards define software maintenance as a post-delivery life-cycle process with defined outcomes and activities. Detailed guidance classifies maintenance into corrective, adaptive, perfective, and preventive work [4], [5]. In the research sense, software evolution denotes the broader, continuous change of software in use, encompassing maintenance and, at times, larger transformations [6], [7]. Such transformations include rearchitecting, large-scale technology migrations, and other proactive changes designed to ensure long-term adaptability and continued relevance, often discussed under reengineering [8], [9].

The distinction between maintenance and evolution becomes increasingly fluid in modern development environments characterized by continuous integration, continuous delivery, and continuous deployment, where software is updated incrementally and frequently to meet evolving needs and technological shifts. In this work, we will use the term “software maintenance and evolution” to indicate the sum of all activities that range from the traditional sense of maintaining a delivered product to reengineering a product under development.

As summarized in Figure 2-1, even though maintenance and evolution are closely related and often overlap in practice, they are still perceived differently: maintenance is often associated with reactive, cost-driven work, while evolution strategically builds on existing software and represents a forward-looking investment. Bridging this gap in perception might be key to enabling more effective collaboration, alignment, and long-term thinking in software-intensive organizations.

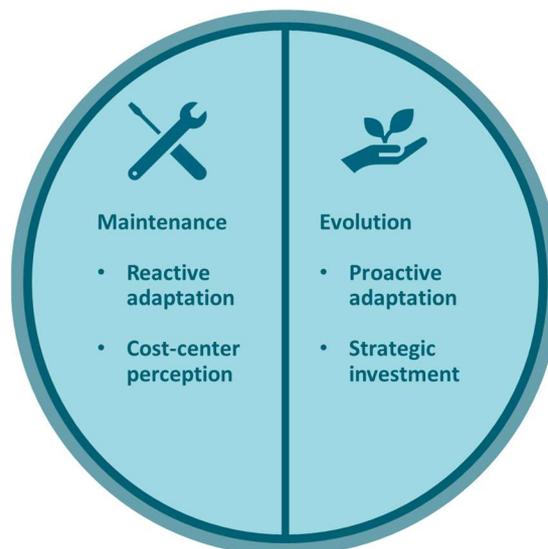


Figure 2-1

In practice, companies face several recurring SMEvo challenges as reported in Figure 2-2. These issues slow teams down and increase risk. Over time, they affect the ability to innovate and compete, and history shows that neglecting evolution in favor of rewriting systems from scratch could lead to strategic failure [10].

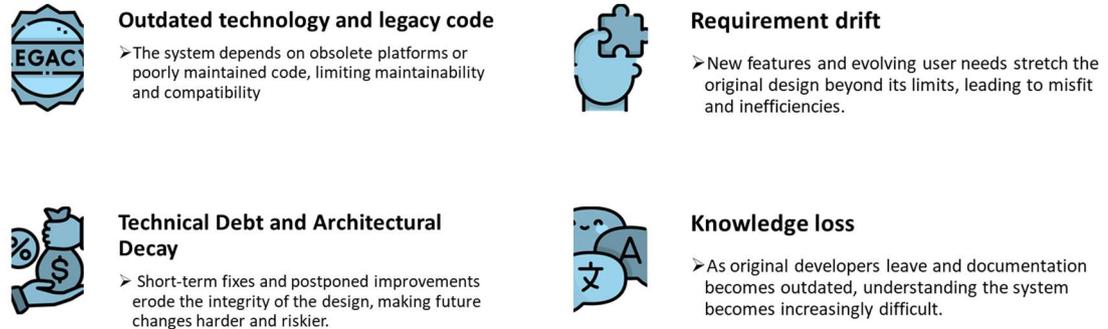


Figure 2-2

Recent developments in SMEvo and the growing emphasis on ecosystem-level collaboration have shaped both the technical and organizational landscape of the field. The next section presents the state of the art and practice in two complementary areas: advances in SMEvo research and the emergence of ecosystem thinking as a strategic approach to sustaining innovation in the field.

2.1 SMEvo

Research and development in SMEvo have been significantly advanced by institutions such as TNO-ESI, CWI, TU/e, and TU Delft. TNO-ESI, in collaboration with Philips, ASML, ITEC, Thermo Fisher Scientific, and VDL, has developed semi-automated methodologies for improving code evolvability through model-based software transformation. These methods focus on model extraction, transformation, and code generation to rejuvenate legacy systems and the use of a code-graph for software visualization and, in combination with generative AI, for code assistance [11], [12].

CWI, in collaboration with Philips and TU/e, has applied metaprogramming techniques to automate large-scale maintenance tasks, enhancing the quality and maintainability of complex software systems [13].

TU/e has focused on code visualization, parser-based methods, and generative AI for understanding and modernizing software systems, with specific interests in layered architecture, dependency analysis, and knowledge graphs [14].

TU Delft has investigated how type systems and name resolution mechanisms can support the verification of systematic code refactoring, with a focus on enhancing code maintainability and reducing technical debt through formal models and algorithms [15].

Together, these institutions and industries contribute to driving progress in the field of keeping software systems adaptable and robust, developing and applying innovative approaches to maintenance and continuous evolution.

We position the work of these institutes within the international research community on software maintenance, evolution, and architecture, represented by conferences such as **SANER**, **ICSME**, **SCAM**, and **ECSA**. These venues have traditionally focused on topics like refactoring, reengineering, architecture design, and long-term system evolution.

2.2 Ecosystem Thinking

In recent years, there has been a growing, though still emerging, interest in more collaborative research practices, particularly in areas such as reproducibility, artifact sharing, and ecosystem-level thinking. For example, an invited ICSME paper from 2016 presented a socio-technical and ecosystemic view of SMEvo, advocating for shared platforms across organizations to manage complexity more effectively [16]. SANER's 2024 Reproducibility Studies and Negative Results (RENE) track encourages the submission of reproducibility studies with shared datasets and artifacts, reinforcing transparency and reuse [17]. While these efforts remain exploratory, they indicate a nascent understanding that effective SMEvo increasingly benefits from community infrastructure, shared tools, and longitudinal cooperation.

The economic impact of thriving software development communities is profound, as demonstrated by the Linux Foundation, Apache Software Foundation (ASF), and Eclipse Foundation. These organizations support numerous open-source projects, including the Linux operating system, Apache technologies (such as the HTTP Server, Hadoop, and Spark), and the Eclipse IDE, which have become essential to many technologies and large-scale enterprises. These projects save companies significant costs, improve efficiency, and foster innovation.

In the realm of SMEvo, several communities contribute directly to modernizing and preserving legacy systems. The [open mainframe project](#) coordinates open-source development around mainframes, providing tooling, training, and collaborative projects that make these long-lived platforms more adaptable to current needs. The [COBOL Programming Community](#) maintains expertise in a language that still supports large portions of financial, governmental, and administrative systems worldwide, ensuring that organizations can keep these systems running while gradually evolving them. The [Software Heritage](#) initiative acts as a universal archive of source code, preserving both legacy and modern software for long-term accessibility and reuse. Together, these communities help legacy systems continue to deliver economic benefits while providing education, infrastructure, and shared resources. They sustain themselves through memberships, donations, sponsorships, event registrations, training programs, and consulting services, which also ensure their growth and long-term viability.

To guide the formation of a collaborative SMEvo ecosystem, we draw on established frameworks for business ecosystem design. One such framework, proposed by the Boston Consulting Group [18], outlines a six-step journey that helps organizations systematically design and launch ecosystems. This approach is particularly relevant for SMEvo, where long-term viability and cross-organizational cooperation are essential. The six steps are:

1. **Define the problem to solve**
Is the problem sufficiently large and complex to warrant an ecosystem approach? Is an ecosystem the right strategic choice, and if so, what type of ecosystem is needed?
2. **Identify key participants**
Who are the essential players and what roles should they assume? Who should act as the orchestrator, and how can they incentivize participation and sustained engagement?
3. **Establish initial governance**

What level of openness is appropriate for the ecosystem? What aspects should the orchestrator control to ensure alignment and quality?

4. **Capture value effectively**

What monetization strategies are viable? Who should be charged, and for what services or contributions?

5. **Overcome launch challenges**

How can the ecosystem reach critical mass? What constitutes a minimum viable ecosystem, and which side of the market should be prioritized initially?

6. **Ensure long-term evolvability**

How can the ecosystem scale, defend itself against competitive threats, and expand into adjacent domains? What mechanisms can protect it from backlash or fragmentation?

This structured approach provides a strategic lens for designing the proposed Dutch SMEvo ecosystem and for analyzing the gap between the current and envisioned situations. It aligns with the broader trends in SMEvo, emphasizing not only technical innovation but also organizational and economic resilience.

Beyond ecosystem design frameworks, an important challenge in SMEvo ecosystems, where multiple solution providers coexist, is achieving the right balance between cooperation and competition among actors. Coopetition theory addresses this tension by demonstrating that collaboration and rivalry can coexist and generate economic value. Bouncken et al. [19] define coopetition as the simultaneous pursuit of cooperation and competition, enabling firms to share resources while differentiating offerings. In strategic interactions, coopetition often emerges as a Nash equilibrium, a state in which each actor adopts the best possible strategy given others' choices, and no one can improve their payoff by acting unilaterally.

An intuitive analogy is traffic lights: drivers comply with “stop on red, go on green” because unilateral deviation offers no advantage. Similarly, ecosystems rely on shared rules and governance to make cooperation the rational choice. Practical examples include coffee shops that jointly organize events and marketing while competing on blends and ambiance [21]. Such cases illustrate how coopetition can enhance joint value creation while preserving competitive incentives.

3 Learnings on the Research Questions

This chapter synthesizes the insights gained from the study in relation to the research questions introduced in Chapter 1. While Chapters 1 and 2 established the motivation, context, and state of the art, the present chapter focuses on the empirical and conceptual findings derived from the project activities. These findings result from a combination of a literature review and three thematic workshops, each addressing one of the core perspectives (organizational, human, and technical) identified as critical for creating or strengthening a SMEvo ecosystem.

The objective of this chapter is twofold. First, it provides informed answers to the research questions, ensuring that both theoretical foundations and stakeholder input support the proposed strategies and recommendations. Second, it links these answers to the long-term ambition of building a viable SMEvo ecosystem, thereby creating a bridge between conceptual understanding and actionable transitions, which are elaborated in Chapter 4.

The discussion is structured into three sections, corresponding to the perspectives defined in the research design:

- **Section 3.1: Organizational Perspective** examines governance, business models, and funding mechanisms that influence ecosystem viability.
- **Section 3.2: Human Perspective** explores roles, competencies, and collaboration dynamics necessary to sustain long-term cooperation.
- **Section 3.3: Technical Perspective** analyzes the current tool landscape, interoperability challenges, and mechanisms for transferring innovation between academia and industry.

3.1 Organizational Perspective

The organizational perspective examines the structural and managerial factors that influence the creation and viability of a SMEvo ecosystem. While technical solutions are essential, the ability to align business models, governance structures, and funding mechanisms determines whether the ecosystem can thrive in the long term.

This section addresses the following research questions:

- **RQ1:** How can conflicting business models be navigated in the context of SMEvo?
- **RQ2:** What strategies can be employed to create compelling business value and cases for SMEvo?
- **RQ3:** What are the best practices for ensuring stable funding for research and the maintenance of shared tools and knowledge in a SMEvo ecosystem?

For each question, we summarize insights from literature and findings from the workshops, highlighting implications for governance, value creation, and long-term viability.

RQ1) How can conflicting business models be navigated in the context of SMEvo?

Managing conflicting business models in a collaborative ecosystem is a well-documented challenge in organizational research. As discussed in Chapter 1, prior research on ‘**coopetition**’ [19] highlights the inherent tension between cooperation and competition and emphasizes the need for structured governance and trust-building. An example of coopetition in an SMEvo ecosystem could be a shared interoperability framework with shared data formats and APIs, enabling tool interoperability while allowing firms to innovate and differentiate through advanced features. Governance mechanisms are key: (i) IP agreements, (ii) tiered contribution models, and (iii) transparent metrics. A tiered model means participants contribute at different levels, such as founding, regular, or affiliate members, with corresponding rights and benefits. In Europe, such models must comply with EU competition law, avoiding market sharing or exclusionary practices.

Building on the discussion of coopetition, frameworks such as the BCG six-step model for ecosystem design [18] emphasize that governance must be complemented by clear value-sharing mechanisms to sustain collaboration without eroding competitive incentives. In this context, Figure 3-1 serves as a value blueprint, illustrating how resources, knowledge, and influence currently flow within the existing SMEvo ecosystem and providing a basis for analyzing gaps and opportunities for joint value creation. The figure maps the types of organizations involved and their overlapping roles, as well as communication channels that illustrate interdependencies among actors. A dashed line marks the ecosystem boundary, separating internal participants from external ones such as customers (from the high-tech equipment industries), research councils, open-source communities, and IT infrastructure providers. Internally, four organizational types are identified: (1) universities and (2) knowledge institutes (which create tools and educate future engineers), (3) IT service providers (which deliver services and tools), and (4) high-tech companies (which apply SMEvo to their own systems, or outsource SMEvo to IT service providers).

Currently, there is no explicit structural coordination in place. Activities such as Special Interest Group (SIG) meetings and thematic events are informally led by TNO-ESI. Collaboration within the ecosystem is also informal and mostly bilateral. The SIG, which has been intermittently active since 2018, serves as a platform for knowledge exchange and tool demonstrations. However, participants have explicitly requested more structured coordination, shared tools and knowledge, and alignment.

Beyond governance and coopetition, structural differences in business models, such as proprietary versus open-source approaches, pose additional challenges for **value creation and sharing**. These business model conflicts influence how organizations capture and distribute value, and therefore require strategies that complement coopetition mechanisms. During the workshops, stakeholders converged on two complementary approaches to manage

business model conflicts and enable coexistence without undermining value creation and sharing. The first approach focuses on **aligning around shared objectives**, such as reducing technical debt and accelerating innovation, to create a common foundation for collaboration. The second approach emphasizes **supporting market-driven coexistence**, recognizing that proprietary and open-source models will persist; interoperability becomes essential to minimize duplication and allow all actors to contribute while maintaining differentiation. These approaches support the ecosystem’s capacity to create and share value by ensuring that governance and interoperability strategies remain adaptable to external dynamics, including regulatory changes and AI-driven SMEvo innovations. The capacity to integrate these responses will determine the ecosystem’s long-term resilience and value proposition.

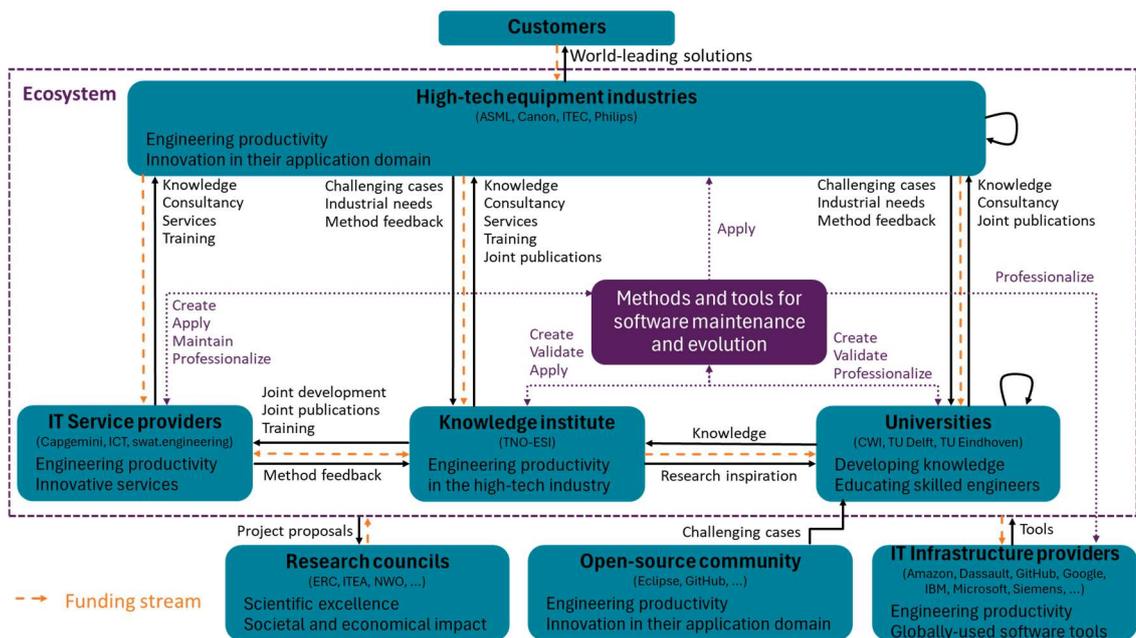


Figure 3-1

While theory emphasizes structured governance as a prerequisite for ecosystem resilience, practice reveals a more nuanced reality. Stakeholders expressed a general willingness to participate, but their readiness and conditions for engagement vary significantly. This gap between intention and implementation underscores the need for a phased transition from the current informal setup to a coordinated structure. As outlined in Chapters 4 and 5, the process begins with clarificatory foundational activities, such as defining scope, roles, and shared objectives, before moving toward formal governance structures and coordination mechanisms. Successfully progressing from informal collaboration to structured governance will be critical for enabling alignment, trust, and long-term resilience.

RQ2) What strategies can be employed to create compelling business value and cases for SMEvo?

Establishing compelling business cases for SMEvo is essential to securing long-term investments and ecosystem stability. Literature on digital transformation [22] emphasizes that value creation in ecosystems depends on aligning technical innovation with business objectives. Additionally, it is important to show that there is a value in the cooperation and in the creation of the ecosystem itself. The BCG framework [18] highlights the need to define value-sharing mechanisms early in ecosystem design. In the context of SMEvo, this means translating technical challenges into business-relevant language and metrics, and defining KPI's at the ecosystem level. ISO/IEC/IEEE 12207 [4] provides a SMEvo framework and language but lacks guidance on ecosystem-level KPIs.

Our SMEvo ecosystem currently lacks a formal strategic plan with ecosystem-level KPIs, but this study initiates one by outlining a shared vision and objectives. As the high-tech industry focuses on innovation, cost, and ROI, it is essential to demonstrate how the shared vision and objectives enable attainable savings and long-term benefits.

The workshop participants expressed that a better understanding of SMEvo's role in business operations is needed at the industry executive levels. Communicating the impact of technical debt, legacy systems, architectural erosion, and knowledge loss in business terms could help clarify the strategic importance of SMEvo.

Another observation from the workshop is that monitoring and evaluating ecosystem performance requires defining KPIs and collecting real data from industrial cases. Sharing these findings will help establish best practices and support evidence-based decision-making.

RQ3) What are the best practices for ensuring stable funding for research and the maintenance of shared tools and knowledge?

Funding streams are currently fragmented and short-term, often tied to individual projects. The stability issue can be addressed through measures such as:

- Sharing the burden of financing across ecosystem partners to avoid over-reliance on single contributors. The workshop participants highlighted this point.
- Bringing in resources from diversified funding mechanisms (e.g., public-private partnerships). As outlined in Section 2.2, leading open-source ecosystems like the Linux Foundation and Apache Software Foundation show how diversified revenue, membership fees, sponsorships, and services ensure stability. These models can guide similar strategies for our SMEvo ecosystem.
- Demonstrating value early via pilot projects and quantified ROI. The workshop participants highlighted this point.

Funding for knowledge, tools, and infrastructure typically comes from a combination of industry stakeholders and public research bodies (e.g., ITEA, NWO, TKI). This shared investment reflects distributed decision-making and mutual responsibility for innovation. To maximize impact, it is essential to engage key influencers across this network—both industry decision-makers and leading professionals. Public co-investment emphasizes societal benefit, so research outcomes must be broadly applicable, extending beyond individual companies to the wider high-tech sector, software-intensive systems, and SMEs, ensuring scalability and generalization.

The key to keeping the ecosystem alive is demonstrating the impact and value of SMEvo. Assets such as presentations and convincing quantitative examples must be readily available on the shared platform. TNO-ESI may need to fulfill, at least interim, a dedicated ecosystem coordinator role to manage these activities.

3.2 Human Perspective

The human perspective addresses the roles, competencies, and interpersonal dynamics required to create and support a collaborative ecosystem for SMEvo. The success of the ecosystem depends on effective communication, trust-building, and the development of skills necessary for long-term cooperation.

This section answers the following research questions:

- **RQ1:** How can effective communication and cooperation be fostered while balancing competition among stakeholders in a SMEvo ecosystem?
- **RQ2:** How can new competency profiles be developed to maintain and evolve software over the next 5 to 10 years?
- **RQ3:** What competencies and roles are necessary to sustain the ecosystem for SMEvo?

For each question, we summarize insights from literature and findings from the workshops, highlighting implications for ecosystem design and governance.

RQ1) How can effective communication and cooperation be fostered while balancing competition among stakeholders in a SMEvo ecosystem?

In complex ecosystems involving diverse stakeholders, such as public institutions, private vendors, open-source communities, regulatory bodies, and end users, stakeholders operate under divergent goals, incentives, and organizational cultures. While collaboration is essential to ensure system viability and innovation, competition for resources, recognition, and strategic advantage can create friction and fragmentation.

The literature identifies several strategies to balance cooperation and competition:

- Understanding Stakeholder Dynamics is crucial. As discussed in the organizational perspective (Section 3.1, RQ1), coopetition theory [19] describes ecosystems in which firms simultaneously compete and cooperate. This requires balancing trust and control mechanisms and leveraging political behaviors such as coalition-building and strategic communication.
- Communication should be treated as a strategic enabler rather than a soft skill. According to IEEE's guidance on communication for engineers (2023)[23], clarity, empathy, and contextual awareness are essential for aligning technical and non-technical stakeholders. Practices such as transparent information sharing, active listening, and feedback loops help reduce uncertainty and adapt strategies.
- Structural and Cultural Mechanisms can institutionalize cooperation. Collaborative governance models, such as joint steering committees, shared roadmaps, and conflict resolution protocols, are effective. Bianchi, Nasib and Rivenbark (2021)[24] highlight the need for innovative models and methods that help stakeholders develop a shared understanding of complex problems and desired outcomes as crucial for effective collaboration. Additionally, boundary-spanning profiles, individuals, or teams that connect siloed groups are key. These profiles facilitate translation between different stakeholder languages (e.g., business vs. technical) and mediate competing interests.

These strategies were echoed in the workshops. Workshops included empathy exercises to help participants understand each other's perspectives. Participants playing the industry role emphasized the relevance of solution-oriented approaches, while participants playing the role of researchers highlighted the need for clarification and refinement. The role of IT service providers was perceived as unclear, with commercial priorities occasionally conflicting with long-term research goals.

In the current situation, communication remains siloed between technical, business, and policy domains. Metrics for assessing and communicating the value of SMEvo are unclear, and there is a lack of shared language or term definitions. The group envisioned an ecosystem where stakeholders are aligned around shared goals, communication is structured and inclusive, and cooperation is incentivized through shared metrics and recognition.

Practical progress depends on creating safe spaces for dialogue, aligning incentives, and building structures that support long-term collaboration.

RQ2) How can new competency profiles be developed to maintain and evolve software over the next 5 to 10 years?

Traditional professional profiles in software engineering are largely process-oriented, reflecting roles tied to lifecycle phases such as developer, maintainer, or acquirer [4]. This perspective overlooks the specificity of software evolution, which is not confined to a single phase but spans significant portions of the product lifecycle and intersects with product management activities. Research on SMEvo demonstrates that these tasks are far from routine; they demand deep system knowledge, reverse engineering expertise, and the capability to integrate existing software with modern architectures [12], [14].

Building on work that extends process standards with evolving product management practices [25] we can explore how professional profiles should evolve to explicitly support SMEvo through cross-functional competencies, e.g., Software Evolution Engineer, SMEvo Architect, Product Evolution Manager, etc.

In workshop 2, we discussed this topic. We identified several systemic challenges in the current situation: a shrinking pool of SMEvo experts, a lack of formal training pathways for modernization of legacy technologies, the low attractiveness of SMEvo profiles to younger professionals, and a fragmented definition of stakeholder roles in the SMEvo process, leading to unclear responsibilities and gaps in accountability. The group envisioned a future ecosystem where new profiles are formally recognized and supported, training programs and certifications are developed for SMEvo-specific skills, and career paths in SMEvo are reframed as strategic and impactful.

Developing new profiles for SMEvo is crucial for maintaining and evolving software-intensive systems. By investing in profile innovation, education, and cross-sector collaboration, the ecosystem can ensure it meets the SMEvo demands of the next decade. Workshops indicated stakeholder readiness to co-create new profiles, contingent on shared vision and support from universities and knowledge institutes.

RQ3) What competencies and roles are necessary to sustain the ecosystem for SMEvo?

Supporting an ecosystem for SMEvo requires more than technical solutions; it demands a diverse, well-coordinated network of roles and competencies. These roles span organizational levels, technical domains, and institutional boundaries. The stability and viability of a SMEvo ecosystem depend on the interplay among actors across organizations, including industry, academia, and IT service providers, each contributing distinct competencies ranging from technical expertise to governance, education, and innovation.

Peter Smits [22] emphasizes that successful digital transformation depends on rethinking organizational roles and competencies. Applied to SMEvo, this means reimagining the ecosystem of roles and skills to support continuous software evolution. This involves:

- Identifying critical profiles.
- Fostering cross-generational collaboration to bridge the gap between institutional memory and emerging technologies.

- Developing new competencies that blend deep technical expertise with systems thinking, communication, and change leadership.

By comparing the current state of the ecosystem with the envisioned future, participants in the workshops identified a wide range of roles essential to sustaining the SMEvo ecosystem. These roles can be grouped into functional clusters, each contributing to a different dimension of the ecosystem:

Strategic and Organizational Leadership

- CTO, R&D Manager, Department Manager: Set vision, define KPIs, allocate resources.
- Product/Project Managers: Align business goals with technical execution.
- Marketing and Sales: Communicate value and secure stakeholder buy-in.

Technical Execution and Integration

- Software Developers, Architects, Engineers: Design, implement, and evolve systems.
- SMEvo Engineers and Architects: Specialize in SMEvo strategies and toolchains.
- Diagnostics and Maintenance Engineers: Ensure system reliability and traceability.

Infrastructure and Tooling

- Tool Developers and Maintainers: Build and sustain SMEvo tools.
- Platform Architects: Manage long-term compatibility and scalability.
- Configuration and Variant Managers: Handle complexity and versioning.

Testing and Quality Assurance

- Test Engineers, Software Testers: Prevent regressions and validate SMEvo outcomes.
- Integration Engineers: Ensure interoperability across components and systems.

Education and Knowledge Transfer

- Professors, Educators, Academic/Fundamental (SMEvo) Researchers: Develop and disseminate new methods.
- Students and Interns: Engage in learning and experimentation.
- Applied (SMEvo) Researchers: Bridge research and practice through applied innovation.

External and Users-Facing Roles

- Support Teams, Consultants: Provide feedback, identify needs, and assess impact.
- IT Service Providers: Deliver specialized SMEvo services and tools.

The viability of the envisioned SMEvo ecosystem depends on a broad and evolving constellation of roles. These roles must be supported by targeted competency development, institutional collaboration, and long-term investment in education and tooling.

3.3 Technical Perspective

Currently, some organizations in the ecosystem own and maintain separate SMEvo tools, each with a unique set of functionalities and different Technology Readiness Levels (TRL). To enable better collaboration within the SMEvo ecosystem, a technical investigation was conducted to map the current landscape, highlighting both the differences and commonalities among tools. This analysis serves as a foundation for exploring interoperability opportunities and synergies. Additionally, the study examines how the ecosystem can facilitate the transfer of academic innovations into industry practice, enabling companies to adopt cutting-edge methods while providing researchers with real-world use cases and valuable feedback.

This section answers the following research questions:

- **RQ1:** How can we understand, compare, and reason about competing diverse technical solutions in the context of SMEvo?
- **RQ2:** What are the most appropriate platforms for cooperation in SMEvo?
- **RQ3:** How can the transfer of innovation between academia and industry be streamlined in the context of SMEvo?

For each question, we summarize insights from the literature and workshop findings, highlighting implications for ecosystem design and asset sharing.

RQ1) How can we understand, compare, and reason about competing diverse technical solutions in the context of SMEvo?

To understand, compare, and reason about the diverse technical solutions existing within our ecosystem, i.e., to navigate the tool landscape effectively, a comprehensive list of tools available across ecosystem parties was compiled. This list contained the following tools: Rascal, Renaissance, R.E.B.O.R.N. (built around Renaissance), and Spoofox, which are owned or maintained, respectively, by CWI, TNO-ESI, Capgemini, and TUD. These tools implement specific methods and reflect broader methodological approaches. This means that to navigate the landscape successfully, a firm grasp of all the methodologies behind the tools is needed.

Interviews with the owners of the tools, except Spoofox², were performed to inquire about their methodologies. Specifically, we asked them to define their methodologies in terms of the concepts, frameworks, methods, principles, techniques, formalisms, and tools they use, based on the definitions provided in [28], which are as follows:

- **Concepts:** Implementation-agnostic representations of core ideas or notions.
- **Frameworks:** Structural models that help organize and relate key elements.
- **Principles:** Broad, general insights that guide thinking and decision-making.
- **Methods:** Structured sequence of steps to achieve a specific goal.
- **Techniques:** Concrete procedures used to carry out individual steps.
- **Formalisms:** Precise ways to represent concepts, relationships, or data.
- **Tools:** Systems that support applying methods, techniques, and formalisms.

The answers in these interviews were collected and analyzed, and a summary of the analysis results is shown in Figure 3-2. This analysis indicated that a large portion of the methodologies are highly similar. The concepts, frameworks, principles, and methods are highly aligned. The concepts they use to address SMEvo are “software analysis” and “software transformation”. Examples of frameworks and methods used to support these concepts include static dependency analysis within and around a software component, as well as capabilities for migrating software to support other libraries.

² The owners of Spoofox did not participate in the workshop or interviews. However, methodological differences for Spoofox were inferred from the literature.

The interviews also revealed some differences in techniques and formalisms across methodologies. Notable differences in techniques include AST rewriting in Rascal and Spoofox versus offset-based source code rewriting in Renaissance and R.E.B.O.R.N. Additionally, Rascal and Spoofox both employ strategic rewriting [29]. Renaissance includes an LLM that can assist with constructing Cypher queries for graph-based dependency analysis.

In terms of formalism support, Spoofox is capable of constructing scope graphs to model name binding and resolution. In contrast, the other tools lack this capability and instead depend on the binding mechanisms provided by their underlying parsers to perform type checking and symbol resolution. Notably, Rascal’s intermediate model, M3, captures, among other things, information that can help resolve the scope of a variable name [30]. This model constitutes a unique formalism within Rascal, as no other tool in the comparison implements a similar intermediate representation. While these differences in techniques and formalisms may aid tool developers in designing efficient and innovative solutions, they do not seem to offer immediate functional advantages for end-users. This is inferred from the fact that the methodologies are highly aligned from principles to methods, which are the levels to which the end-user (industry) is primarily exposed (cf. Figure 3-2).

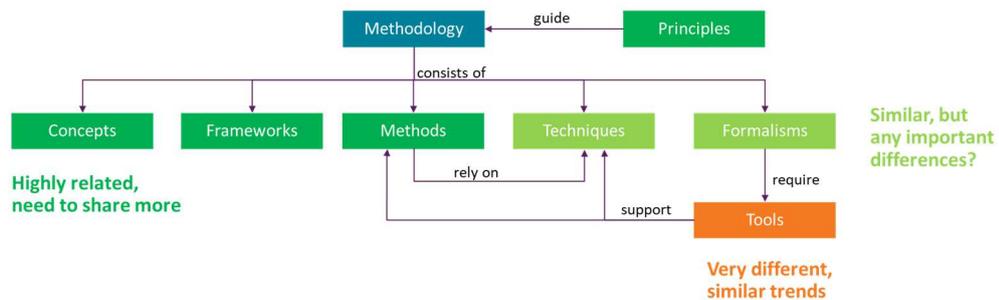


Figure 3-2 - Result of methodology interviews with company representatives

The last topic of the interviews was discussing the tools themselves. Responses indicated that the tools differ significantly in their implementation, but follow similar trends. All the tools were investigating the use of external parsers with multi-language support, such as Doxygen and Tree-sitter. Furthermore, external querying and visualization were mentioned as topics worth investigating. Lastly, there is growing interest and ongoing work in extending these tools to support various forms of intelligent assistance. This includes, for example, the use of LLMs to aid Cypher queries in Renaissance and the ambition to develop libraries of predefined refactorings. Additionally, there are ongoing efforts to develop engines for analysis and transformation rules, as well as to integrate these tools into CI/CD pipelines.

In conclusion, this information enables navigation of the current tool landscape and was used to inform the participants in the workshops. Open questions about similarities, significant differences, and collaboration were raised. This discussion was used as the basis for the following research question.

RQ2) What are the most appropriate platforms for cooperation in SMEvo?

Effective collaboration is seen as challenging in a landscape fragmented by diverse tools. Users must choose a tool, which requires trade-offs based on the functionalities most relevant to their needs. Once a tool is selected and applied successfully, its results are often not reusable in workflows based on other tools. From the perspective of tool maintainers, effective collaboration may involve providing more support or sharing maintenance tasks, disseminating cutting-edge solutions, and preventing duplicate work if another tool already has an existing solution.

After discussing the current tool landscape with the workshop participants, a move towards the solution space was made by exploring different architectures and platforms that could enable collaboration among ecosystem participants. We presented each breakout group with four possible architectures, along with the option to propose their own, and asked them to select the best solution. The group itself determined the context of what constituted a “best solution.” They were tasked with defining the criteria. At the end of the exercise, they presented their results and argued in favor of a specific solution.

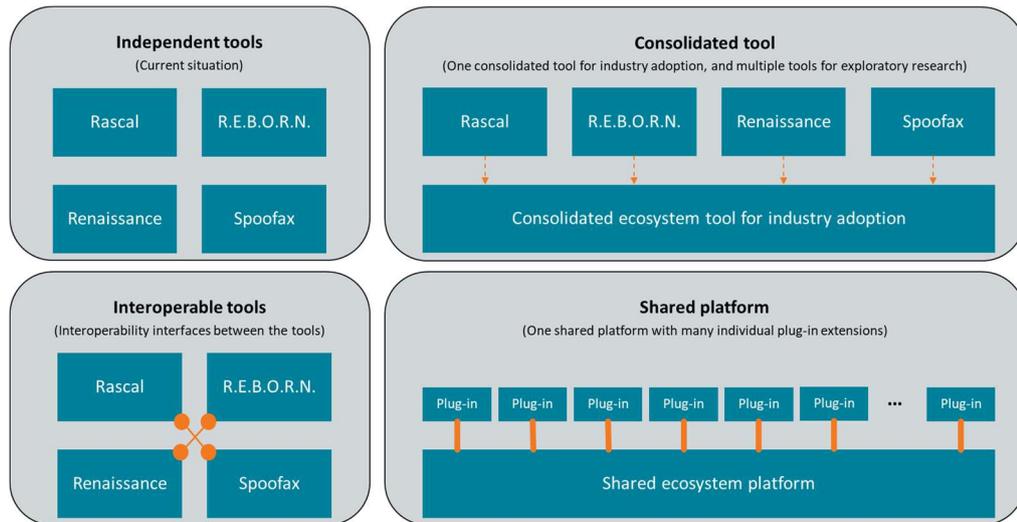


Figure 3-3

The following four architectures were given (see Figure 3-3):

1. **Independent tools.** Essentially, the current situation would remain unchanged.
2. **Consolidated tool.** Every existing ecosystem tool would remain independent. One of the existing tools would be used for industry adoption and would consolidate capabilities from various existing tools.
3. **Interoperable tools.** Every existing ecosystem tool would remain independent, but would put effort into creating an interface that other ecosystem tools can use. This way, a connection can be made through this interface, making all the tools interoperable.
4. **Shared platform.** A cooperatively built environment where each individual ecosystem organization can provide unique functionalities as plug-in extensions. A shared platform would provide reusable, shared infrastructure and utilities, as well as opportunities to combine plugins from different providers.

The breakout groups proposed two more architectures (not shown in Figure 3-3):

- **One tool.** Keep one of the existing tools and eliminate all others.
- **Layered tools.** Following the pattern of R.E.B.O.R.N. being built around Renaissance, try to build another tool that is built around both R.E.B.O.R.N. and, for example, Rascal.

Echoing the opinion already expressed by SMEvo practitioners in a previous survey [31], the outcome of the exercise was that the ideal solution was a “Shared platform”.

The way to get there was to work on the interoperability of tools, as the “Interoperable tools” architecture was the most feasible solution in the immediate future. Every group independently came to this conclusion. They also agreed that as the tools became more interoperable, they would naturally move towards a shared platform due to the growing interoperability. From this

alignment, a possible transition path could be created, starting with independent tools and progressing to interoperability. If interoperability were a great success, opportunities to move towards a shared platform could be explored; however, building a new shared solution in parallel with currently existing tools was deemed too expensive.

The exercise yielded 22 criteria for evaluating architectural options to support the ecosystem’s technical transition. These were then analyzed and grouped into six overarching themes:

Desired architecture	1. Does the architecture bring value to all current parties in the ecosystem?
	2. Does the architecture stimulate collaboration within the ecosystem?
	3. Does the architecture increase the overall usability of the tool(s)?
	4. Is the architecture maintainable?
Transition	5. Is it technically and financially feasible to realize this architecture?
	6. Do we, the parties within the ecosystem, feel like we want this ecosystem?

Of these criteria, the first four specify the desired architecture, whereas the last two concern the cost of transitioning to the situation under focus. From these criteria, it can be concluded that while aspects such as usability, maintainability, collaboration, and value are important, feasibility and support from the parties are equally, if not more important. Without addressing the latter two aspects, the transition towards a new situation will not happen.

Threats to validity

The reason that interoperability was chosen was based on the self-defined criteria of the groups, which introduces a degree of subjectivity in defining the “best” solution. Additionally, some participants noted that the architectural options presented (Figure 3-3) were described in ways that allowed for multiple interpretations, potentially influencing the evaluation process. These two factors can be considered threats to the validity of the conclusions, given their interpretive nature. Nevertheless, all groups independently converged on the same path forward. To mitigate this threat, clarifying questions were posed during the presentation round, and the resulting discussions converged on a shared understanding and consensus regarding the general approach.

RQ3) How can the transfer of innovation between academia and industry be streamlined in the context of SMEvo?

Innovation is a critical and iterative process that unlocks new opportunities for the industry. The technical workshop raised the question of how to streamline innovation to benefit both industry and academia, enabling industry to capitalize on opportunities and academia to gain feedback on the applicability of their research.

Industry Perspective

The industry parties expressed a need for education. It is not a given that their employees directly understand the underlying concepts and uses of the innovation. Competence development at multiple levels could offer a potential solution. Competence development throughout one’s career would certainly be beneficial, but educating future employees would be even more valuable. This would entail more courses on innovation in SMEvo at both the university and applied university levels.

Academic Perspective

Academic parties expressed that funding is their most significant need. They stated they struggle to secure funding for SMEvo, despite industry indications of interest in this topic. With more stable funding, the transfer process is expected to improve. There will be more research yielding results, and funding partially from industry makes the research more attuned to industry's actual needs.

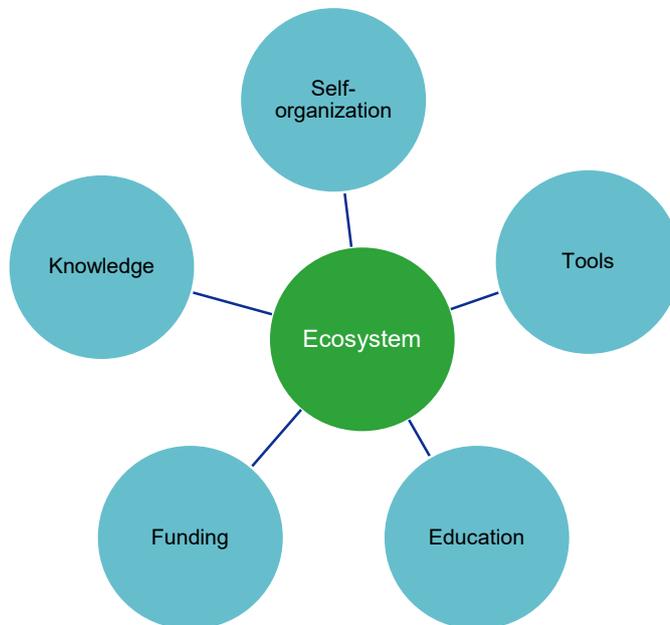
In conclusion, the transfer of innovation from academia to industry in the context of SMEvo can be streamlined by establishing and maintaining stable funding structures between the two parties. The ecosystem could play a central role here, both in connecting the parties and in disseminating knowledge. Secondly, educational material tailored to the needs of SMEvo must be created for learners at various levels, from undergraduate university students to professionals. This material needs to be distributed both as university courses and as competence development programs.

4 Transition areas

During the three workshops, we identified five key transition areas that need to be addressed to build a viable ecosystem for SMEVos. The names of these five key transition areas are:

- Self-organization
- Knowledge
- Tools
- Funding
- Education

The presentation order of the transition areas has no particular meaning.



For each transition area, we continue with a subsection describing the following three aspects:

- Current situation (as-is)
- Envisioned situation (to-be)
- Identified actions to bridge the gap between these two situations.

The identified actions can usually be categorized into 3 groups:

- Elaborate to collect and clarify information within the ecosystem;
- Establish to enhance cooperation within the ecosystem;
- Disseminate to reach out to outsiders of the ecosystem

In the next chapter, we identify the dependencies between the actions from all transition areas.



4.1 Self-organization

This transition focuses on how the ecosystem organizes itself to come to life. These aspects need to be addressed to facilitate cooperation on the exciting SMEvo content.

This transition relates to the following research questions from Section 1.1:

- Organizational perspective:
 - How can conflicting business models be navigated in the context of SMEvo?
 - What are the best practices for ensuring stable funding for research and the maintenance of shared tools and knowledge in a SMEvo ecosystem?
- Human perspective:
 - How can effective communication and cooperation be fostered while balancing competition among stakeholders in a SMEvo ecosystem?
 - What competencies and roles are necessary to sustain the ecosystem for SMEvo?

4.1.1 Current situation

Summary: “Staff from the organizations meet each other and sometimes collaborate”

In various organizations, staff members involved in SMEvo see considerable benefits and interesting challenges in the SMEvo field. These individuals meet sporadically and occasionally collaborate on joint projects. There is a shared belief in the importance of SMEvo for company efficiency, effectiveness, and competitiveness.

There is also a desire to share more knowledge, collaborate more, and enhance SMEvo practice. In particular, there is an interest in creating or strengthening an ecosystem to advance the field of SMEvo. However, many questions remain about how to organize and shape such a collaboration.

4.1.2 Envisioned situation

Summary: “The organizations share a clear vision and structurally benefit from each other”

The vision of SMEvo shared by organizations in the ecosystem is clearly expressed and widely promoted. There is visibility beyond the ecosystem, enabling opportunities for further collaboration. The vision expresses clarity on the scope, challenges, and commonalities, and is clear about the role of the SMEvo ecosystem.

The organizations in the ecosystem are in close contact with each other and structurally benefit from each other. The openness, transparency, and trust within the ecosystem enable the mitigation of adverse effects on the ecosystem. Especially where competition and tensions may arise, quick and professional interventions are in place.

4.1.3 Identified actions

For elaboration, the following actions have been identified:

- Define the scope and vision of the ecosystem. This needs to be documented in a manifesto.
- Define the roles and responsibilities within the ecosystem. This includes coordinators, sponsors, owners, and performers.

- Define a roadmap for the ecosystem. This includes who authors, who owns, who contributes, who harvests, and who substantiates.

In this project, we have taken the first steps that need to be further expanded with the help of organizational experts.

For establishment, the following actions have been identified:

- Decide to participate in the ecosystem. This requires the involvement of decision-makers from each organization in the ecosystem.
- Set up ecosystem coordination and focused working groups.
- Get to know each other better within the ecosystem. This helps to foster trust and an open culture in the ecosystem.
- Intensify cooperation within the ecosystem.

For dissemination, the following actions have been identified:

- Prepare materials (slides, poster, report) to tell the story of the ecosystem.
- Invite small and medium-sized enterprises (SMEs) to the ecosystem.
- Investigate further opportunities to expand the ecosystem and establish connections (nationally and internationally).

4.2 Knowledge

This transition emphasizes the wealth of knowledge on SMEvo available within the ecosystem. Being successful in applying SMEvo in practice goes beyond the availability of software tools.

This transition relates to the following research questions from Section 1.1:

- Technical perspective:
 - How can the transfer of innovation between academia and industry be streamlined in the context of SMEvo?

4.2.1 Current situation

Summary: “Knowledge is shared ad hoc among organizations”

Universities and research institutes document part of their knowledge in the form of academic publications and conference presentations, but these are not easily accessible to practitioners. In-depth technical knowledge is typically shared within the context of bilateral projects involving only a subset of the ecosystem’s organizations.

In addition, more high-level success stories are shared irregularly:

- Industrial conferences, like Bits and Chips;
- Meetings of the Special Interest Group (SIG) on software rejuvenation;
- Other incidental contacts.

4.2.2 Envisioned situation

Summary: “Knowledge is actively shared, maintained, and used across organizations”

The ecosystem collaborates to maintain and use knowledge on SMEvo beyond high-level success stories. There is a managed knowledge base on SMEvo that is well accessible to researchers and practitioners, which includes:

- Examples;
- Guidelines;

- Publications;
- Best practices.
- Methodologies (principles, frameworks, methods, techniques, representations)

Additionally, it should include rules on how to share and cooperate within the ecosystem.

4.2.3 Identified actions

For elaboration, the following actions have been identified:

- Align the technical definitions in a taxonomy (incl. software maintenance, software evolution, technical debt, etc.). This could lead to a scientific joint publication by the ecosystem.
- Create a catalogue of the SMEvo methodology (especially principles, concepts, frameworks, and methods).
- Create a catalogue with real-world applications of SMEvo. This should include the original problem statement, representative code snippets, the people and roles involved, the applied approach (methods, tools, etc.), the rationale for this approach, any quantitative metrics, and the technical and business results obtained. The approaches should include methodologies from the ecosystem and alternatives available internationally outside of the ecosystem. This should help both researchers and users who want to decide which approach to use.
- Create a mapping between people in the ecosystem, the various methods and tools, and their role (e.g., tool developer, tool user, researcher, experienced consultant).

In this project, we have taken the first steps to be further expanded with the assistance of methodological experts.

For establishment, the following actions have been identified:

- Set up the technical infrastructure for the knowledge base. This includes technical decisions (such as which platform to use) and managerial decisions (including visibility and access rights).

For dissemination, the following actions have been identified:

- Collect information to onboard people who start to use the ecosystem tools and to exchange tips and tricks within the ecosystem.
- Explain the need for the ecosystem SMEvo methodologies internationally outside the ecosystem.

A particular concern is to ensure that the knowledge is not only collected and recorded but also effectively utilized and updated. For instance, ease of searching for relevant topics is a key aspect to consider. On the one hand, it should be as easy as possible to share and contribute new information; on the other hand, there should be people who actively monitor and improve the structure.

4.3 Tools

This transition focuses on the software tools for SMEvo. Apart from the technical aspects that need to be aligned, joint work on tools can also foster human bonding between both tool developers and tool users within the ecosystem.

This transition relates to the following research questions from Section 1.1:

- Technical perspective:
 - How can we understand, compare, and reason about diverse technical solutions in the context of SMEvo?

- o What are the most appropriate platforms for cooperation in SMEvo?

4.3.1 Current situation

Summary: “Multiple uncoordinated tool initiatives by individual organizations”

There are currently 4 SMEvo tools being developed within the ecosystem, viz., Renaissance (by TNO-ESI), R.E.B.O.R.N. (by Capgemini), Rascal (by CWI), and Spoofox (by TUD). These developments are mostly uncoordinated; only R.E.B.O.R.N. was built around Renaissance. For many participants in the ecosystem, the purpose of and need for the various available tools are not clear. The technicalities, features, functions, and characteristic differences between the tools are generally unknown.

These SMEvo tools are being used in industry to some extent. Industries are relying on and benefitting from their functionality in certain areas. Different organizations in the ecosystem use different tools determined by influential engineers, their past experiences, or business contracts.

4.3.2 Envisioned situation

Summary: “Joint work on tools that support various research and industrial applications”

High-quality SMEvo tools are available to the organizations in the ecosystem, both for research and industrial applications. The tools support SMEvo at various levels, ranging from low-level refactoring to architectural restructuring. Moreover, the purpose and need for each tool are clear to the organizations in the ecosystem.

The diversity of tools is managed through ecosystem agreements between tool developers. In particular, the tools are interoperable, facilitating the integration of parts from multiple tools.

4.3.3 Identified actions

For elaboration, the following actions have been identified:

- Investigate the differences and commonalities between the ecosystem tools (including the corresponding techniques and formalisms) in more detail. In particular, make it insightful to all members of the ecosystem.
- Position the ecosystem tools with respect to tools that are available internationally outside of the ecosystem. This includes both widely used scripting languages, such as Python, and specialized tools like OpenRewrite, AST-grep, and Coccinelle. In particular, make it insightful to all members of the ecosystem.
- Clarify ownership and usage rights of the tools within the ecosystem. Open-source tools like Rascal and Spoofox have a different nature than tools like R.E.B.O.R.N. and Renaissance. A particular point of attention should be the rights of joint development work within the ecosystem.

In this project, we have taken the first steps that need to be further expanded with the help of technological experts.

For establishment, the following actions have been identified:

- Define and implement clear interfaces that make the ecosystem tools interoperable. The interface definitions should include shared data formats. Particular attention is needed to quality attributes, such as maintainability.

- Investigate opportunities to collaborate on shared libraries for the ecosystem tools to enhance synergy within the ecosystem.
- Improve the usability of the ecosystem tools for users in the ecosystem.

For dissemination, no actions have been identified for the SMEvo ecosystem.

For all identified actions, it is a particular attention point to distinguish more between analysis and transformation functionality, where analysis is aimed at understanding the software code. In contrast, transformation seeks to change it.

Automated transformation is an additional phase after analysis and involves additional efforts and risks. In some cases, there is no need to automate the transformation once a good automated analysis has been performed.

4.4 Funding

This transition focuses on funding SMEvo activities within the ecosystem. The bottom line is that funding crucially depends on the value drivers and perceived business value, both for applying SMEvo methodologies and for collaborating within the SMEvo ecosystem.

This transition relates to the following research questions from Section 1.1:

- Organizational perspective:
 - What strategies can be employed to create compelling business value and cases for SMEvo?
 - What are the best practices for ensuring stable funding for research and the maintenance of shared tools and knowledge in a SMEvo ecosystem?

4.4.1 Current situation

Summary: “Funding the research on and application of SMEvo is a struggle”

To initiate or fund an SMEvo activity in the industry, a solid business case is required. To this end, it is indispensable for management to fully understand the business value of SMEvo. The deciding management always has a limited budget, so they must balance short-term and long-term activities to ensure a healthy business operation. The business case for SMEvo activities is not easy, as there is a lack of direct metrics or success criteria. The effects of SMEvo are diffuse and long-term, which often makes it difficult to explain the business value and convince decision-makers.

4.4.2 Envisioned situation

Summary: “Investments in research on and application of SMEvo clearly pay-off”

The SMEvo tools and methodologies are intensively applied within the ecosystem, and data is systematically collected to validate their effectiveness, e.g., applicability, viability, desirability, business value, and feasibility. The available success stories on applying SMEvo are convincing, and the value and return on investment are clear to decision-makers. External drivers, such as the European Cybersecurity Act (CSA), serve as an additional propelling force.

The application of the ecosystem's SMEvo methodologies grows steadily. There are stable funding streams for SMEvo research, SMEvo tool maintenance and development, and SMEvo applications. This provides the required momentum and scale for further research and

development on SMEvo. The experiences from the abundance of SMEvo applications inspire the type of problems that are addressed by the SMEvo research teams.

4.4.3 Identified actions

For elaboration, the following actions have been identified:

- Clarify the business value of SMEvo. In particular, measure and estimate the business value in prior SMEvo cases (see also the transition on Knowledge).
- Clarify the business value of cooperation in the SMEvo ecosystem.
- Identify opportunities that require the application of SMEvo techniques, e.g., software with a longer lifetime for sustainability and regulations on security.
- Clarify how to set up stable funding streams for research and tool development.

In this project, we have taken the first steps that need to be further expanded with the assistance of business experts.

For establishment, the following actions have been identified:

- Set up stable funding streams for research and tool development.
- Distribute the tools investments within the ecosystem. For example, let companies pay for tool usage if they do not directly contribute otherwise.
- Define a business model for cooperation in the ecosystem.

For dissemination, the following actions have been identified:

- Organize events such as an “SMEvo day” to attract new companies/departments and decision makers.
- Create advertisement campaigns based on storytelling to inform the world about the goals and capabilities of the tools and methodologies.

4.5 Education

This transition focuses on lifelong learning and attractive career paths. These are essential to structurally increase the number of people who participate in SMEvo activities.

This transition relates to the following research questions from Section 1.1:

- Human perspective:
 - How can new profiles be developed to maintain and evolve software over the next 5 to 10 years?
 - What competencies and roles are necessary to sustain the ecosystem for SMEvo?
- Technical perspective:
 - How can the transfer of innovation between academia and industry be streamlined in the context of SMEvo?

4.5.1 Current situation

Summary: “SMEvo is taught at a small scale by some universities and by TNO”

Software-related educational programs focus on green-field engineering and rarely address SMEvo methodologies. We are only aware of the following SMEvo courses in the Netherlands:

- “Software Language Engineering” course by Tijs van der Storm at Groningen University as part of the bachelor's program in computing science. The focus is on techniques and concepts for constructing software languages using Rascal.

- “Software Evolution” course by Jurgen Vinju at the University of Amsterdam as part of the master's program on software engineering. The focus is on maintaining and evolving software systems using language engineering techniques with Rascal.
- “Software Legacy” course at TNO-ESI as part of their competence development program for the high-tech equipment industry. The focus is on analyzing and transforming large industrial code bases using Renaissance.

Students often lack awareness of the importance of SMEvo for the industry, and career paths in SMEvo are not clearly defined. SMEvo is usually perceived as a less appealing topic compared to technologies like new languages, data science, artificial intelligence, etc. (although many of these technologies are also relevant for SMEvo).

4.5.2 Envisioned situation

Summary: “Learning material for a career in SMEvo is widely available and used”

All software-related bachelor's and master's programs in the Netherlands, both at universities and at applied universities, include courses on SMEvo in addition to green-field engineering. Also, for lifelong learning, there are various opportunities to support continuous development in SMEvo, including self-study materials.

Students are well aware of the importance of SMEvo for the industry. Software engineers who are well-educated in SMEvo readily find employment in the industry, and they help the industry to adopt new SMEvo innovations. All software engineers in the Dutch industry can apply standard SMEvo methodologies as part of their work, and their managers support them in this endeavor. Additionally, there are sufficient SMEvo experts to perform and support increasingly more complex SMEvo applications.

4.5.3 Identified actions

For elaboration, the following actions have been identified:

- Categorize the SMEvo profiles and their required capabilities.
- Collect the existing learning materials on SMEvo.

In this project, we have taken the first steps that need to be further expanded with the help of educational experts.

For establishment, the following actions have been identified:

- Identify combinations of target audiences, types of courses, and desired learning outcomes (knowledge, skills, abilities, attitudes). The audience may range from inexperienced students to senior staff, and includes both technical and non-technical profiles. Particular attention is needed for Dutch companies that need to train personnel in departments that are located outside the Netherlands.
- Design and develop learning materials (instructional design). This should include self-study materials, such as videos, sandbox exercises, and interactive playgrounds.

For dissemination, the following actions have been identified:

- Create awareness of attractive career paths in SMEvo.
- Create awareness of available learning materials for SMEvo.

5 Master Plan

This chapter introduces the master plan, an overarching strategy that guides a phased approach to strengthening and formalizing the SMEvo ecosystem. Its phased nature allows space for further clarification where alignment is still in progress, and the long-term shared vision continues to evolve through exploration. The master plan encompasses three key phases:

- Phase 1, which focuses on preparatory foundational activities.
- Phase 2, which formalizes the governance and funding of the ecosystem.
- Phase 3, which will define the concrete steps for operating and expanding the ecosystem.

Phase 1 defines a set of coordinated actions, priority deliverables, and decision points that will guide stakeholders through the initial stages of alignment, cooperation, and strategic planning. The goal is to assess the scope of application of existing solutions, the feasibility and value of collaboration, build trust, and secure stakeholders' commitment.

Phase 2 establishes the structural and organizational foundations required for the future operation and expansion of the ecosystem. This phase culminates in the creation and approval of the Phase 3 roadmap, which will translate validated insights and stakeholder commitments into concrete actions for the ecosystem operation and expansion.

The remainder of this chapter describes the roadmap for executing Phases 1 and 2.

This phased approach reduces risk, ensures business relevance, and builds a strong foundation for long-term success.

This chapter follows this structure: drawing from the transition areas outlined in Chapter 4 and applying the BCG 6-step framework, we identify a set of **foundational activities** (and corresponding actions from the transition areas) that should be prioritized. We define the tangible results of those activities as **priority deliverables** (Section 5.2), and we represent them in an entity-relationship diagram that shows how those deliverables contribute to achieving the vision depicted by the transition areas. Each deliverable is linked to a specific action from the transition areas, and the interdependencies between the actions are mapped in a **Dependency Diagram** (Section 5.3). The priority deliverables are scheduled within the **Phase 1 and Phase 2 roadmap** (Section 5.4). Section 5.5 lists the **competencies needed** to execute the Phase 1 and Phase 2 roadmap.

5.1 Foundational activities

The transition areas outlined in Chapter 4 represent a comprehensive vision for the SMEvo ecosystem. However, implementing all identified actions at once would be overly ambitious and risky. Some issues, such as clarifying the ecosystem mission, proving ROI, and defining governance, require foundational activities before significant investments can be justified. To identify these foundational activities and structure a phased approach to ecosystem strengthening and formalization, we applied the BCG 6-Step Business Ecosystem Design Framework as a diagnostic tool.

Initially intended for ecosystem design, the framework was used here to analyze the current state, identify critical unknowns, and determine which actions should come first to reduce uncertainty and enable alignment. This analysis informed the Phase 1 and Phase 2 roadmap

by highlighting high-leverage priorities across six dimensions. Below is the result of the BCG 6-step framework application, with the foundational activities that need priority in execution:

1. Problem Definition: What is the problem we want to solve? Is the problem big enough, and is the ecosystem the right choice?
 - o The contextual problem is to establish the capabilities (i.e., competencies, cooperating parties, and methodologies) to effectively and efficiently maintain and evolve complex industrial software systems.
 - o Specifically, the pressing problem is scaling the solutions and capabilities existing within the ecosystem to address the software maintenance and evolution challenges faced by our industrial stakeholders.
 - o Although providing solutions and capabilities to support the industry need in SMEvo is considered a substantial and critical challenge, the **scope of applicability for the solutions already existing** within the ecosystem remains unclear.
 - o Furthermore, the **benefits of strengthening and formalizing the ecosystem**, as well as the type of ecosystem required (solution-oriented vs. transaction-oriented), are not yet clear.
2. Ecosystem Composition: What are the players and roles? Who should be the orchestrator? How can the orchestrator motivate the other players?
 - o While the current ecosystem players are identified, their **roles and responsibilities** require clearer definition.
 - o TNO currently acts as an interim orchestrator and aims to incentivize participation through pilot projects that demonstrate the value of collaboration.
3. Governance Model: What should be the initial governance model of your ecosystem? What should the orchestrator control?
 - o A cooperative governance model is preferred; however, the ecosystem's **vision, scope, and mission** lack clarity.
 - o The boundaries of orchestrator control remain uncertain, particularly regarding **strategies to balance cooperation and competition** and ensure tools' **interoperability**.
4. Value Capture: How can you capture the value of your ecosystem?
 - o Realizing value depends significantly on **solution positioning** and the selected **business model**.
5. Chicken-Egg Problem: How can you solve the chicken-egg problem? What does it take to achieve critical mass? What is the minimum viable ecosystem? Which side of the market should you focus on?
 - o Adopting a phased strategic approach is a good way to solve the chicken-egg problem and achieve critical mass before significant investments.
 - o The minimum viable ecosystem consists of an innovation chain that includes a knowledge institute, an implementation partner, and an industrial partner.
 - o Achieving critical mass depends on value realization, which in turn is influenced by **solution positioning** and **business model** selection.
 - o Initial efforts may focus on the Netherlands or on specific use cases, such as code quality.
6. Evolvability and long-term Viability: How can you ensure the evolvability of your ecosystem?
 - o Establishing a shared governance model and interoperability standards is essential to reducing silos and fragmentation. Minimizing these barriers is critical for achieving the critical mass and resilience required for ecosystem viability and expansion.
 - o Transitioning from short-term funding mechanisms (e.g., grants) to sustainable long-term models, such as subscriptions or strategic partnerships, combined with centralized knowledge-sharing practices, is necessary to scale the current state toward an envisioned ecosystem capable of meeting industry needs over time.

By systematically applying the BCG 6-step framework to the transition areas identified in Chapter 4, we matched each foundational activity to concrete actions that address the most

critical uncertainties and priorities for ecosystem development. For each dimension of the framework, we selected actions that directly enable progress and reduce risk:

- **Problem Definition:** Actions such as “Define the scope and vision of the ecosystem” were selected because they clarify what the ecosystem aims to solve and ensure all stakeholders share a common understanding.
- **Ecosystem Composition:** “Decide to participate in the ecosystem” and “Define the roles and responsibilities within the ecosystem” were chosen to establish a clear organizational structure and commitment.
- **Governance Model:** “Set up ecosystem coordination and focused working groups” and “Clarify ownership (and usage rights) of the tools” address the need for effective governance and management of shared assets.
- **Value Capture:** “Clarify the business value of SMEvo (existing solutions)” and “Clarify the business value of cooperation” were prioritized to demonstrate tangible benefits and motivate investment.
- **Chicken-Egg Problem:** “Position the ecosystem tools” and “Create a catalogue with real-world applications” help build critical mass by showcasing available solutions and their applicability.
- **Evolvability and Long-Term Viability:** “Set up the technical infrastructure for the knowledge base” and “Define a roadmap for the ecosystem” actions ensure the ecosystem can adapt and grow over time.

The following actions were selected because they directly address the critical uncertainties and priorities identified through the BCG framework analysis, ensuring that the ecosystem’s development is both strategic and feasible:

	action	from section
1	Position the ecosystem tools	4.3.3
2	Clarify ownership (and usage rights) of the tools	4.3.3
3	Create a catalogue with real-world applications (of SMEvo)	4.2.3
4	Define the scope and vision of the ecosystem	4.1.3
5	Clarify the business value of SMEvo (existing solutions)	4.4.3
6	Clarify the business value of cooperation	4.4.3
7	Decide to participate in the ecosystem	4.1.3
8	Define the roles and responsibilities within the ecosystem	4.1.3
9	Set up ecosystem coordination and focused working groups	4.1.3
10	Set up the technical infrastructure for the knowledge base	4.2.3
11	Define a roadmap for the ecosystem (Phase 3 roadmap)	4.1.3

5.2 Priority deliverables

Figure 5-1 illustrates the priority **deliverables** associated with the priority actions listed in the table above and selected from the transition areas of the Chapter 4. The Phase 3 roadmap is the final, most important deliverable of the Phases 1 and 2 execution. However, the other intermediate deliverables also carry significant value because they establish shared assets and reduce uncertainty; thus, we capture their output in tangible deliverables.

Figure 5-1 gives the list of priority deliverables for the transition areas described in Chapter 4, using an entity-relationship diagram. Only four of the transition areas, i.e., self-organization, knowledge, tools, and funding, are present in this diagram. The education transition was not identified as having foundational actions by the analysis based on the BCG 6-step framework. For this reason, the education transition is acknowledged but intentionally deferred to a later stage of the ecosystem's development, as we first focus on establishing the value of

cooperation, validating the methodologies used, and aligning on governance before committing to building shared assets (i.e., tools and educational materials) within the ecosystem.

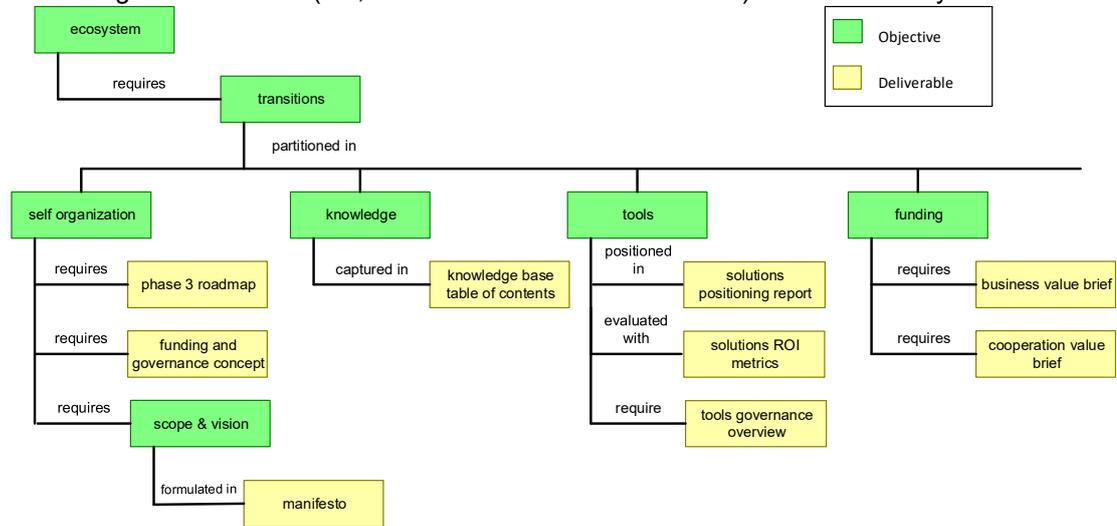


Figure 5-1 Entity-Relationship Diagram of Deliverables

Each transition is associated with specific deliverables as follows:

- Self-organization
 - **Phase 3 roadmap (final deliverable):** A comprehensive, actionable plan for operating and expanding the SMEvo ecosystem. The deliverables below support the development and validation of this roadmap.
 - **Funding and governance concept:** A strategic framework for establishing sustainable financial support and effective governance structures within the SMEvo ecosystem, ensuring coordinated collaboration, resource allocation, and long-term viability for all participating organizations.
 - **Manifesto:** A public declaration of the vision, mission, and guiding principles of the SMEvo ecosystem. It is a shared statement that aligns all participating organizations around common goals and values, providing clarity and direction for collaboration and development within the ecosystem.
- Knowledge
 - **Knowledge base (table of contents):** A proposed structure for a shared and evolving body of SMEvo knowledge. It defines relevant domains and key topics to guide collective knowledge development.
- Tools
 - **Solutions Positioning Report:** A comprehensive analysis that positions existing ecosystem tools both by their underlying technical approaches (such as analysis, rewriting, parsing) and by their practical application domains (such as legacy migration, architecture recovery). This report identifies technological gaps and overlaps, clarifies the scope of applicability of current SMEvo solutions, and provides guidance on integrating these tools with or complementing traditional approaches within and outside the ecosystem.
 - **Solutions ROI Metrics:** A set of quantitative and qualitative indicators designed to measure the return on investment (ROI) of SMEvo solutions within the ecosystem. Where historical data is available, these metrics are derived from past project outcomes to assess effectiveness, cost savings, lifecycle benefits, and business impact. If historical data is lacking, new pilot projects should be initiated with the explicit goal of collecting ROI evidence,

- ensuring that future investments are guided by robust, empirical insights and supporting evidence-based decision-making.
- **Tools governance overview:** A summary of ownership and licensing models to support collaboration and interoperability.
- Funding
 - **Business Value Brief:** A narrative summary of the value proposition of SMEvo solutions, explaining how they address technical debt, legacy system maintenance, and architectural erosion to enhance organizational effectiveness, cost efficiency, and long-term systems maintainability. The brief draws on both quantitative and qualitative evidence, such as cost savings, productivity improvements, risk mitigation, and innovation acceleration, to help decision-makers understand the strategic impact of SMEvo initiatives and justify investments.
 - **Cooperation Value Brief:** A framing of the benefits of joint investment and collaboration, emphasizing resource sharing, knowledge exchange, and development of interoperable tools. It recognizes that cooperation enables access to both industry funding and public research subsidies, supporting larger, more impactful projects and fostering innovation across the ecosystem.

Together, these deliverables establish the structural and strategic foundations necessary to transition from exploring the feasibility of the SMEvo ecosystem to its execution. They enable stakeholders to assess the value of available technical solutions and collaboration, thereby building trust and aligning around shared priorities.

They form the foundation for executing Phases 1 and 2 of the master plan. Their interdependencies are visualized in the Dependency Diagram below (Section 5.3, and their scheduling is detailed in the Phase 1 and 2 roadmap (Section 5.4).

5.3 Dependency Diagram

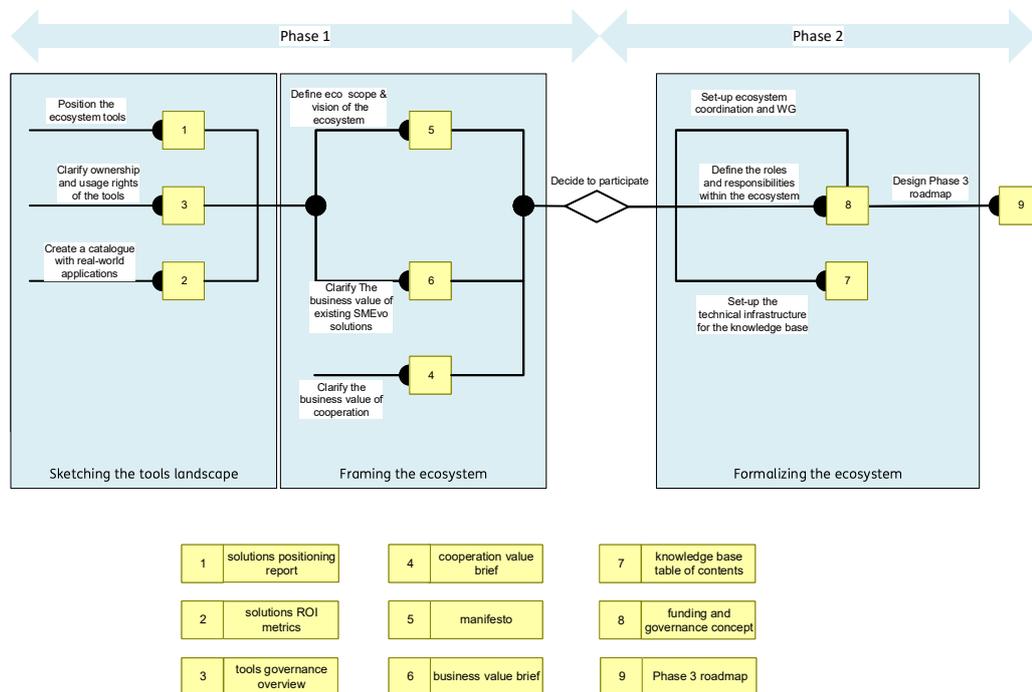


Figure 5-2 Diagram of Dependencies

Figure 5-2 sketches a diagram, illustrating the logical dependencies among the priority actions that are selected from Chapter 4 and produce the deliverables described in Section 5.2. The diagram shows the actions that should occur in Phases 1 and 2 of the master plan. Phase 1 addresses two key foundational activities, i.e., Sketching the tools landscape and Framing the ecosystem, which are executed as follows:

- **Sketching the tools landscape** by *positioning the ecosystem tools, creating a catalogue of real-world applications, and clarifying ownership and usage rights of the tools*. These activities will yield the deliverables: *solutions’ positioning report, solutions’ ROI metrics, and tools governance overview*.
- **Framing the ecosystem**, which depends on sketching the tools landscape, is executed by *defining the scope and vision of the ecosystem, clarifying the business value of existing SMEvo solutions, and clarifying the business value of cooperation*. These activities will yield a *manifesto* and two briefs for business and cooperation values.

Once these initial activities are completed, they converge at a **decision point for all the ecosystem stakeholders** to *decide to participate* in the ecosystem (this decision point is derived from an action in the Self-Organization Transition in Section 4.1.3). This marks the collective commitment to move forward in building the ecosystem.

Following this decision, Phase 2 starts focusing on:

- **Formalizing the ecosystem** by *setting up the ecosystem coordination and focused working groups, defining the roles and responsibilities within the ecosystem, and setting up the technical infrastructure of the SMEvo knowledge base*. These activities will yield a *funding and governance concept* and a *knowledge base table of contents*.

The final step of Phase 2 is to:

- **Design the Phase 3 roadmap**, which consolidates all insights, decisions, and structures into a coherent, actionable plan for ecosystem development.

The diagram of Figure 5-2 clarifies the interrelationships among actions, helping coordinate stakeholders' contributions and plan accordingly based on dependencies and priorities.

5.4 Phases 1 and 2 roadmap

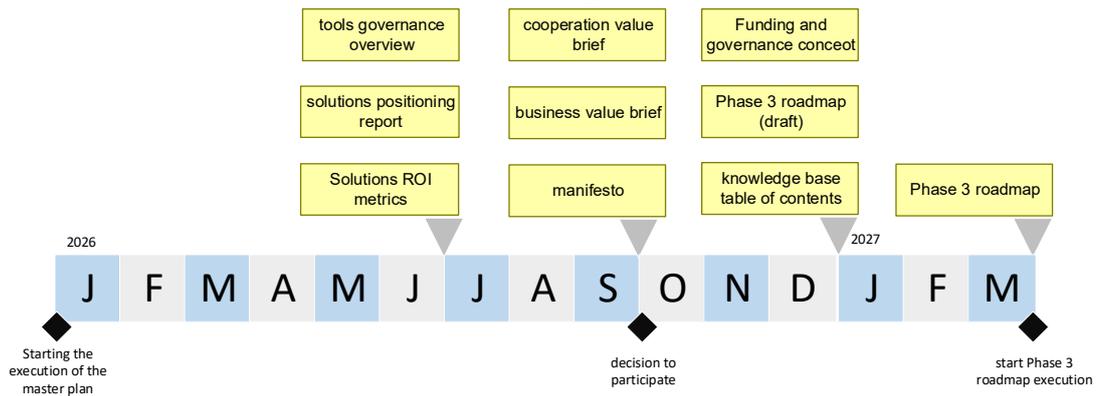


Figure 5-3 Phases 1 and 2 Roadmap Timeline

Figure 5-3 presents the Phases 1 and 2 roadmap, outlining the timeline for realizing the deliverables described in Section 5.2, from January 2026 to March 2027³. The roadmap includes two key decision points that structure and validate progress: the decision to participate in ecosystem building and the alignment with the Phase 3 roadmap before execution begins.

The end of June 2026 marks the first milestone, with the delivery of the “solutions positioning report”, “tools governance overview” and “solutions ROI metrics”.

End of September 2026 culminates in the articulation of a shared vision, the business value of SMEvo, and the value of cooperating, leading to the first decision point:

- Decision to participate – stakeholders formally commit to ecosystem development based on an aligned vision and value.

At the end of December 2026, coordination structures and a draft version of the ecosystem Phase 3 roadmap will be delivered.

End of March 2027 marks the final milestone, with the decision to

- Start the ecosystem Phase 3 roadmap execution – stakeholders assess the readiness and endorse the final roadmap.

³ The dates are subject to approval by management and stakeholders.

5.5 Competency Framework for Phases 1 and 2 Roadmap Execution

The Phases 1 and 2 roadmap sets the foundation for building a viable SMEvo ecosystem. Its success depends on more than the individual expertise of the single organizations; it requires cross-organizational knowledge and coordinated contributions.

To achieve this, we invite ecosystem partners to mobilize and share their complementary strengths. This is not just desirable but essential.

Stakeholders are encouraged to contribute competencies in the following areas:

1. Program & Governance

- Ability to design and document governance structures (roles, responsibilities).
- Competence in roadmap planning and dependency mapping.
- Skills in facilitating alignment and decision-gate preparation.
- Conflict resolution and consensus-building across stakeholders.

2. Technical Analysis & Tool Positioning

- Understanding of SMEvo principles.
- Ability to analyze and compare tools by techniques and application domains.
- Knowledge of interoperability strategies and interface design principles.
- Awareness of CI/CD integration and toolchain maintainability considerations.

3. Knowledge Architecture & Documentation

- Competence in taxonomy design and metadata standards.
- Ability to structure and maintain a knowledge base (table of contents, contribution workflows).
- Skills in synthesizing research outputs into practical guidance and templates.

4. Business & Funding Strategy

- Ability to frame cooperation value and articulate business cases.
- Competence in ROI analysis and lifecycle cost modeling.
- Familiarity with funding mechanisms (public-private funded projects, EU programs, membership models).
- Skills in extracting value cases from stakeholder interviews.

5. Cross-Cutting Competencies

- Interviewing and evidence gathering (structured questioning, qualitative synthesis).
- Strategic communication: translating technical and business insights into clear narratives.

6 Conclusion

This report examines the challenge of strengthening and formalizing the existing ecosystem for SMEvo in the Dutch high-tech industry, as a joint response to the urgent need to effectively and efficiently support the evolution of long-lived, software-intensive systems. Through workshops, stakeholder alignment, and literature review, we identified key enablers and barriers to establishing a collaborative SMEvo ecosystem.

To ensure a comprehensive understanding, the study was structured around three core perspectives (organizational, human, and technical), each addressing distinct but interconnected dimensions of ecosystem creation and development. These perspectives guided the formulation of research questions and shaped the design of the workshops, enabling a multi-faceted exploration of the ecosystem's potential.

From an organizational perspective, the study highlights the importance of collaborative governance, clear ecosystem role definitions, and stable funding mechanisms. The current ecosystem operates through informal collaborations and ad-hoc initiatives, which, while valuable, lack the structural support required for scalability and resilience. The envisioned future calls for a formalized ecosystem with defined responsibilities, a shared vision, and a roadmap that aligns stakeholder interests.

The human perspective reveals that effective communication, trust-building, and competence development are critical elements for initiating and sustaining the ecosystem. The workshops demonstrated stakeholders' interest in shared goals, contingent on clarity of ecosystem roles, return on investment, and mutual understanding. The emergence of new professional profiles, such as SMEvo engineers and tool developers, reflects the evolving demands of software evolution. Education and lifelong learning are essential for attracting and retaining talent. The integration of SMEvo topics into academic curricula and professional development programs is a necessary step forward.

Technically, the ecosystem is currently characterized by a diverse landscape of tools and methodologies, each with unique strengths and limitations. The analysis of tools such as Rascal, R.E.B.O.R.N., Renaissance, and Spoofox reveals significant overlap in principles and methods, suggesting opportunities for interoperability and shared development. The consensus among stakeholders favors an interoperability-first strategy, which strikes a balance between feasibility and long-term aspirations for a shared platform. This approach enables incremental progress while preserving the autonomy and innovation of individual tool developers.

Five key transitions (self-organization, knowledge, tools, funding, and education) were identified as foundational to the development of a sustainable SMEvo ecosystem. Each transition outlines a shift from fragmented, ad-hoc practices to structured, collaborative approaches. For example, self-organization transitions from informal interactions to coordinated governance; knowledge evolves from scattered insights to a shared, accessible base; tools transition from isolated initiatives to interoperable solutions. Funding shifts from uncertain streams to value-driven investment models, and education expands from niche offerings to integrated, lifelong learning pathways. These transitions are not isolated efforts but interdependent steps that collectively enable ecosystem growth.

The master plan developed in this report provides a structured and phased approach to initiating the ecosystem. It translates the five identified transition areas into a set of actionable

deliverables. It includes a roadmap that outlines the sequence, dependencies, and decision points for the first year of implementation.

In conclusion, the report highlights the opportunities and challenges associated with strengthening a collaborative SMEvo ecosystem and proposes steps to address them. It establishes strategic alignment, technical interoperability, and human capacity as foundational pillars. The following steps involve mobilizing stakeholders, securing commitments, and advancing the roadmap outlined in the master plan. By doing so, the Dutch high-tech industry can transform software maintenance from a reactive necessity into a proactive enabler of innovation and competitiveness. The proposed ecosystem model offers a replicable and scalable framework for software evolution and maintenance, with the potential to inspire similar initiatives in other regions and sectors.

7 Annex: Maintenance Costs

In this annex, we estimate maintenance costs using typical planning assumptions for the Netherlands and the COCOMO II model [32].

We will use these definitions:

Symbol	Name	Description
C	Codebase size	
SU	Software understanding	SU is expressed quantitatively as a percentage. If the software is rated very high on structure, application clarity, and self-descriptiveness, the penalty for software understanding and interface checking is 10%. If the software is rated very low on these factors, the penalty is 50%. SU is defined in the COCOMO II model Table 1.
UNFM	Programmer's relative unfamiliarity with the software	The UNFM parameter is applied multiplicatively to the software understanding effort increment. If the programmer works with the software every day, the 0.0 multiplier for UNFM will not increase their software understanding. If the programmer has never seen the software before, the 1.0 multiplier will add the full effort required to understand the software. UNFM is defined in the COCOMO II Model Table 3.
MCF	Maintenance Change Factor	The MCF represents the percentage of the code added or modified each year. This value is expected to be $\leq 20\%$ in software development projects that involve reuse and are not a significant rewrite of an existing product. This guideline is based on the COCOMO II Model Definition Manual, Section 2.3.5
MAF	Maintenance Adjustment Factor	Multiplier for maintenance sizing, accounting for SU and UNFM. $MAF = 1 + \frac{SU * UNFM}{100}$
M_{size}	Maintenance size	Yearly maintenance work in equivalent MLOC $M_{size} = C * MCF * MAF$
P	Productivity	Productivity is the equivalent of lines of Code a developer delivers per unit time (Person Month). It depends on the context and the task; we use data from Table 7-1 in [28] and assume a high range of productivity for embedded code, command and control, and scientific systems.
FTE	Effort	This is the effort needed to execute the maintenance tasks per year in FTEs $FTE = \frac{M_{size}}{12 * P}$
FL	fully-loaded € per FTE-year in the Netherlands	This is the gross salary from Glassdoor , plus 30% social charges, and 8% holiday allowance. We compute this value for the average gross salary of €60K, and the top salary of €91K.
AC	Annual cost	There is a minimal and a maximal annual cost depending on the type of FTE employed and whether they perceive an average or a top salary. $Annual\ cost = FTE * FL$

The calculation is done with the following values:

Symbol	Value	Name	Description
C	10 MLOC	Codebase size	
SU	10%	Software understanding	A rating of 10% indicates that the code is highly structured and clear.
UNFM	0,1	Programmer's relative unfamiliarity with the software	A 0.1 rating indicates that the programmers are between completely familiar and mostly familiar with the code.
MCF	15%	Maintenance Change Factor	Within the ≤20% for incremental development (No new or spin-off product)
MAF	1,01	Maintenance Adjustment Factor	Cf. formula above
M_{size}	1,515	Maintenance size	Cf. formula above
P	300 LOC/PM	Productivity	data from Table 7-1 in [28] and assume a high range of productivity
FTE	420	Effort	Cf. formula above
FL	€83K	fully-loaded € per FTE average salary	
	€126K	fully-loaded € per FTE top salary	
AC	€34M	Annual cost min	Cf. formula above
	€53M	Annual cost max	

This yields an average annual cost of 43 million.

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