Proceedings of the Design Society, Volume 5: ICED25
https://doi.org/10.1017/pds.2025.10328

Towards a readiness level-based development of methodical approaches (MxRL)

Christian Köhler, **Tobias Mahl and Jonas Mohke**

Saarland University of Applied Sciences, Germany

christian.koehler@htwsaar.de

ABSTRACT: Developing methodical approaches, from methods and concepts to algorithms and comprehensive methodologies, requires application-specific expertise and a structured procedure to ensure both workflow efficiency and validity. This contribution introduces a conceptual model for assessing the maturity of methodical approaches through ten predefined readiness levels. By achieving level-specific sub-goals, the model aims to systematize the development process while progressively increasing maturity, ultimately yielding more effective approaches. This novel concept not only supports the structured development of methodical approaches, but also facilitates their comparability and evaluation. The necessity of the proposed concept is substantiated through a systematic literature review, while its functionality is critically evaluated and validated by experts and using multiple examples.

KEYWORDS: design methods, research methodologies and methods, decision making, design engineering

1. Introduction

The engineering field is driven by rapid and highly dynamic technical and organizational advancements. This results in a continuously growing number of engineering publications over the past 20 years (Schneider et al., 2023). In the field of engineering design Eisenbart et al. (2024) identified 204 contributions with focus on the development of new tools and methods to support design processes only at ICED conferences 2017 and 2019. Although scientific contributions of this kind attract widespread attention, they are often not yet fully mature (Gericke et al., 2020). Furthermore, not all of these supports are widely or consistently adopted in real-world environments (Jagtap et al., 2014); many see limited use before being overshadowed, and comparisons among methods are challenging due to variations in frameworks and objectives (Franke & Deimel, 2004; Gericke et al., 2020; Wallace, 2011). To leverage their potential, a structured, not only problem-oriented development of these approaches is indispensable. For researchers and potential users, it is often difficult to determine whether a methodical approach is a prototype or has been tested and implemented in practical applications, even after careful review of the literature.
The Technology Readiness Level (TRL) represent a solution to a comparable problem of technology development (Sadin et al., 1989; ISO 16290:2013). Even if this concept was transferred to other domains, there was need for adaptation. There are a number of cases in the literature that address certain weaknesses. For example, the TRL assessment criteria are too vague for the chemical industry (Buchner et al., 2019). For natural resources management, however, use as a guideline is possible but not as a targeted development path (Cupp et al., 2023). In the context of software method development domain specific adaptations were also necessary (Holt et al., 2014).
A framework for the development and maturity assessment of methodical approaches in engineering based on the TRL concept could create transparency with regard to the development status and help to make the associated development processes more structured and the developed approaches more useful and transferable. Thus, this paper aims to answer the question what a readiness level approach similar to

the TRL should look like for methodical approaches in the field of engineering, as the use of TRL does not seem suitable for determining the maturity of methodical approaches since the TRL levels are not specific enough and leave too much room for interpretation.

To provide a consistent understanding of "methodical approaches" in this contribution, it's essential to clarify and differentiate related terms such as method, concept, tool, methodology, framework, and algorithm (for definitions see e.g. (Blessing & Chakrabarti, 2009)). Here, these terms are summarized as methodical approaches, defined as systematic procedures aimed at solving predefined (partial) problems by following sequential, interrelated steps or activities. This broad categorization facilitates an unified assessment of approaches, allowing to assess these diverse approaches without compromising the integrity of their individual meanings. This is feasible because each term shares a fundamental objective: systematically solving a given problem.

This contribution answers the research question by presenting the development work (section 2) and the resulting solution proposal (section 3). First, a systematic literature review (SLR) analyzes and evaluates the current state of approaches assessing the maturity of methodical approaches. Based on identified needs and derived requirements, a conceptual model for assessing the maturity level of methodical approaches is introduced, critically evaluated, affirmed by experts, and demonstrated through multiple examples. In addition to two cases, 20 methodical contributions, initially presented at the 23rd International Conference on Engineering Design (ICED), serve as application examples to demonstrate the practical value of the model, while also refining the initial version.

2. Development and validation process

2.1. Research methodology

The research approach chosen for this article is based on DRM Type 3 'Development of Support' of Blessing & Chakrabarti (2009). Research Clarification (RC) and Descriptive Study I (DS-I) were essentially based on a systematic literature review, which showed that there is as yet no closed and specifically applicable support. The support was developed as part of the Prescriptive Study (PS). In the Descriptive Study II (DS-II), the approach was reviewed and refined in the form of an initial study. There, the developed approach was first applied retrospectively to finished projects of the research group in order to test its general applicability. Based on the knowledge gained, the approach was refined, evaluated and optimized with the help of qualitative interviews with external experts. In addition, a sample of relevant contributions to the 2023 ICED conference was evaluated using the approach in order to compare consistency with current practices.

Although PS and DS-II were iterative, this chapter describes RC, DS-I and DS-II for reasons of comprehensibility. The following chapter presents the optimised result of the PS as a closed approach, so that the requirements of DRM type 3 for support "can be used by others" are met.

2.2. Systematic literature review (SLR)

To gain insights into current development processes for methodical approaches, readiness levels, and maturity models-and to explore existing approaches for assessing the maturity of methods similar to the TRL concept-a SLR following the PRISMA framework was conducted (Lame, 2019). The procedure, including search phrases and the databases searched, is shown in Figure 1. In order to identify adequate search phrases and initial papers to kick-off the systematic review Google scholar was used as the initial search engine and database. After collecting a deeper insight into the topic the systematic review was started which yielded 13,178 hits in the first phase. After removing duplicates, papers with unfitting titles and abstracts 22 publications were left for full text reviews. Finally, 7 publications fitted the criteria of the review. Criteria for inclusion were language, the type of the publication and the context of the publication. Only English or German publications in conferences or journals were included. In addition, only papers dealing with the development (process) for methodical approaches or maturity models / readiness levels for methodical approaches were accepted.

The literature review was extended using the "snowballing"-method by Wohlin (2014). By backward and forward snowballing, two more publications were included in the review. In total, the SLR identified 6 different development processes in the context of methodical approaches (see Table 1). However, the SLR did not provide any results on corresponding maturity models or readiness models or their development in

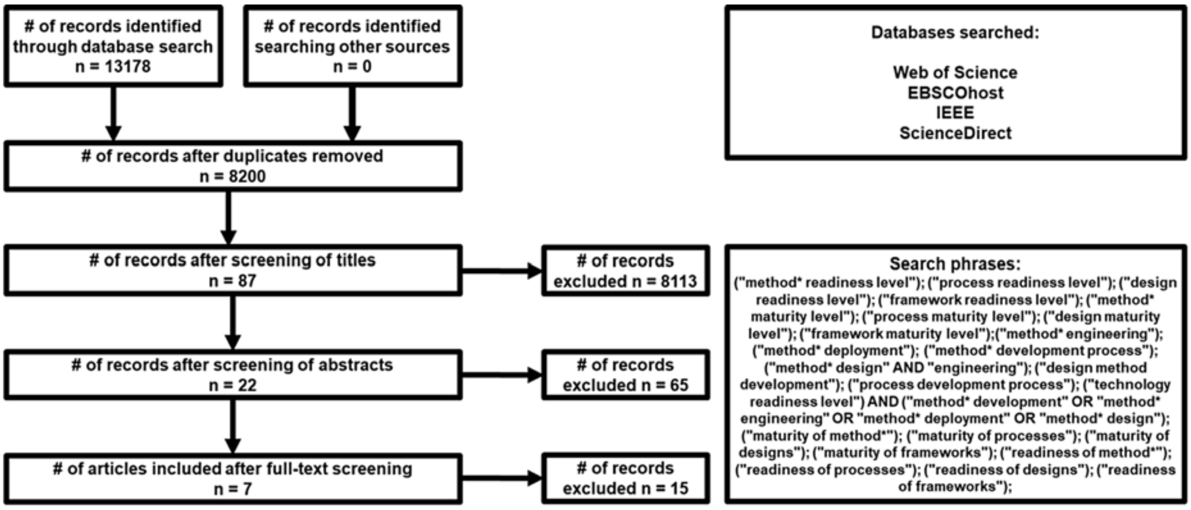

Figure 1. SLR process based on Lame (2019)

the context of the research. It should also be emphasized that the publications of Proenca (2016), Goldkuhl and Karlsson (2020), Boorsma et al. (2022) are all based on Peffers et al. (2007). Furthermore, the results come from the field of information systems and are more about the development of IT solutions (methods). A publication with specific reference to the development of methods or tools or modifications for engineering methods could not be identified.

Table 1. SLR results overview of the identified development processes ([1] (Peffers et al., 2007), [2] (Hecklau et al., 2020), [3] (García-Mireles et al., 2012), [4] (Aguiar & Jugend, 2022), [5] (Gökalp et al., 2023), [6] (Rosemann & Bruin, 2005) and [7] (Blessing & Chakrabarti, 2009))

[1]	[2]	[3]	[4]	[5]	[6]	[7]	Meta phases
Identify problem and motivate	Identify requirements	Inception	Planning	Identify existing work	Identify problem	Research clarification	**Initiation**
Define objectives of a solution	Identify method-bases				Analyse state of the art	Descriptive study I	
Design & development	Development	Elaboration Construction	Development	Development	Development	Prescriptive study	**Development**
Demonstration Evaluation	Testing Improvement	Deployment	Evaluation	Test	Test Evaluation / improvement	Descriptive study II	**Validation**
Communication		Maintenance			(Communication)		**Transfer**

Although the approaches originate from other domains, they have a similar structure to the DRM approach (Blessing & Chakrabarti, 2009). This allows the conclusion to be drawn that the approach and sub-goals in the development can be generalised (last column in table 1): First of all, a problem must be identified for which there is a motivation to solve it. The problem is then examined in more detail and influencing factors and existing solution approaches are identified through literature research. Then, on the basis of the knowledge gathered, existing approaches are developed further or new developments are started. These are then tested and evaluated. In addition, the development processes provide for an iterative approach, so that a revision takes place after new knowledge has been gained, for example in prototypical use case applications. The methods should then be transferred into practice. Furthermore, it is notable, that only two of the approaches also support the transfer of the method into application.
As part of the initial search in the process to identify the search phrases for the SLR, 2 publications were found that deal with readiness levels for design (Design Readiness Levels) (Poorkiany et al., 2016) and methods (Method Readiness Levels) (Ivanova, 2023; Mansfield, 2019). The Design Readiness Levels are focused on the area of product development. The Method Readiness Levels refer to the research project "COMPASS", but, focus more on methods in the sense of information technology (as described in the introduction). However, the structure of the two models served as inspiration for the development of the Methodical Approaches Readiness Level (MxRL) concept presented in chapter 3.

In summary, the SLR did not identify any existing specific system for the development of methodical approaches or for classifying their development maturity, similar to the TRL concept. A need is therefore seen to close this gap in order to make the development processes and their maturity more comprehensible and transparent.

2.3. Validation

Three different approaches were employed to assess according to Pedersen et al. (2000) the theoretical structural and theoretical performance validity of the developed concept and its MxRL stages: The evaluation involved a retrospective comparison using a previously developed method and methodology by the authors, interviews with external experts, and a retroactive application to third-party contributions presented at ICED23.

2.3.1. Retrospective application to previously developed methodical approaches

In contribution 1 (C1), an existing method for the analysis and optimization of processes, products and systems was further developed so that it could be applied in a similar but broader context, since a number of problems arose when using the original version of the method. This was done as part of a cooperative research project with another university and several companies. The development of the adapted method was carried out iteratively and followed a micro cycle of analyze, test & observe and optimize. A comparison of the documented procedure for the development of the adapted method with the process shown in Table 3 showed that the method achieved and was published at MxRL 4, as the method was prototypically tested, evaluated and optimized by the developers on a real use case.

The second comparative contribution (C2) is an iterative methodology designed to transition linear business models into circular ones. This approach integrates various methods across multiple phases, including a company and environmental analysis, a creativity stage, and a validation stage. Developed within an enterprise-collaborative research project, the methodology has been applied within multiple company structures, primarily to small and medium-sized enterprises. The methodology achieved also MxRL 4, although not all model aspects were fully addressed. Notably, the iterative process of application, evaluation, and optimization, mentioned in Table 3, was not consistently complied with during the development. However, several development steps show strong alignment with the developed concept process. The methodology was tested in both simulated scenarios by the authors and real industry environments with third-party involvement, thereby meeting the primary MxRL outcomes of the developed concept.

When applying the model to familiar methods (C1) or methodologies (C2), as described above, the model provides a good applicability since most of the development steps are known in detail. Although C1 and C2 were not initially developed with the model, a strong similarity with the MxRL concept could be observed, while still deviating from the described optimal procedure. In summary, the following insights could be derived when applying the model to C1 and C2:

- **Retroactive MxRL assignment** - Despite the original development process differs from the proposed one, both final and interim results can be retroactively assigned to an MxRL.
- **Identification of gaps** - It can also be evaluated at which point the original process has gaps that could require revision or make problems visible.
- **Process improvement potential** - By revealing these gaps, the model offers the possibility to refine the original development process.
- **Subjectivity in qualitative gaps** - The descriptions of the MxRL defined at the time of the test left too much room for subjective interpretation, which is why they were subsequently reformulated using more objective criteria.
- **Insight requirements** - The application of the concept is easy but a great amount of development process knowledge needs to be available to be able to apply the method properly.

2.3.2. Expert interviews

As part of the validation process, the authors conducted four semi-structured qualitative interviews with external experts who were not involved in the development of the MxRL approach (for information about the experts see Table 2). The aim of the interviews was in particular to identify weaknesses in the developed concept and to obtain general feedback on the research work.

Table 2. Short presentation of the persons interviewed

Interviewees	Degree / Field	Experience / Level	Comment
IP 1	Professor / Enigineering	Research & Industry / high	Expert was selected because of his wide-ranging experience in the academic and non-academic field.
IP 2	Ph.D. / Engineering	Industry & Research / high	The person was selected because his case exemplifies a scientifically grounded development of a method and its subsequent successful transfer to industry.
IP 3	Ph.D. student / Engineering	Research & Industrial / mid	He offers a process-oriented perspective on the next planned development steps of a methodology, supporting the evaluation of its usefulness for ongoing research and development efforts.
IP 4	M. Sc. / Economics	Industry / low	She gained first experiences in the context of developement of methodologies in an industrial context.

The developed concept was presented to all of the interview partners, who were then asked to compare it with their previous work and experience. They were specifically requested to evaluate its completeness and logical structure, identifying any potential weaknesses. Finally, they were all invited to assess the overall benefits. The interviews were held as an open conversation, without a specific catalogue of question. In this meaning, each interviewee received the same pitch and was able to ask questions about the approach before stating their opinion and further recommendations.

The main findings from the interviews are briefly summarised below. All interviewees reacted highly positive to the proposed concept and consider the approach of maturity-orientated structuring of a development process for methodical approaches to be helpful. IP3 particularly emphasized the possibility that the developed concept could contribute to an assessment of external publications in a SLR, contributing to a weighting or rating of captured contributions depending on their acquired MxRL. IP3 and IP4 explicitly noted that such an approach would have helped them to structure their development work in a more targeted way, although already applying the widely known DRM (IP3) or the approach according to Peffers et al. (2007) (IP4). The structural organisation of the concept was also seen as coherent by all interviewees. However, IP1, IP2 and IP4 noted that in practical application, several steps may be combined or merged, which in the end serves to fulfil a higher readiness level. Nevertheless, they recommended that each of the MxRL should be explicitly presented for reasons of orientation. In addition to this confirmatory feedback, weak points were also identified that led to adjustments to the concept:

- The initialisation phase was also included in the model with its own maturity level (IP1, IP2).
- The testing of the transfer elements training and documentation was integrated into appropriate maturity levels, so that the determination of the transferability of methods is now a logical part of the maturity levels for validation (IP1, IP2, IP4).
- The wording of the intermediate readiness levels was adapted so that the potential imperfection of the methodical approach in function and applicability becomes clearer (IP1) and the increase in maturity in the late stages become more apparent (IP1, IP2, IP3).
- The wording was also adjusted to reduce the subjectivity of each phase (IP3).
- The phases were adapted to ensure the developed concept can be applied across a wide range of methodical approaches while respecting their differences, resulting in more generalized phases (IP3).

2.3.3. Application on third-party papers

To evaluate the applicability of the developed concept, 20 ICED23 conference papers on methodical approach development were randomly selected. The papers' development and validation procedures were examined for alignment with the MxRL concept. All papers achieved MxRL 1 & 2, but lacked information for MxRL 3 categorization. Seven papers were categorized as MxRL 4, assuming some intermediate steps were undocumented, suggesting that publications often occur from MxRL 4 onwards. The key findings from the analysis of the papers are listed below:

- Initial development procedures are generally similar, but not all papers explicitly outline a comprehensive methodical approach. Early MxRL is evident in documented cases, while MxRL 2 requires redefinition for simulated testing of development outcomes.
- Conference publications often omit some development steps necessary for assessing MxRL, likely due to page limits, making retrospective assessments from an external perspective challenging (but possible), as crucial information may be missing.
- The MxRL system, if applied, could enhance transparency by enabling authors to self-classify their results.

3. Approach for assessing the readiness level of methodical approaches (MxRL)

The result of the described development work is based on the conviction that the result of research on and development of methods is the transfer of the method into application. The proposed assessment scheme should be suitable for all forms of methodical procedure development: New developments of methods, development of variants of existing methodological approaches as well as adaptation of existing approaches to e.g. changed context. The term ‘development of methodoical approaches’ was chosen because the approach can be used in the context of developing methodologies, methods, algorithms or tools.

The approach described is based on the necessary development phases for methodical approaches derived in section 2.2 (Table 1 & 3): Initiation, development, validation and transfer. Besides that, it is

Table 3. Methodical approaches readiness levels (MxRL) with process phases and activities

No.	Phase	Activities	MxRLs
I	Initiation	1. Identification of problem and need2. Determination of requirements”	**MxRL 0** Needs and requirements for method development are confirmed and documented.
II	Development	1. Development of methodical approach concept, working materials, aids, tools and application instructions2. Simulated testing and iterative optimization”	**MxRL 1** Prototypical method concept is available. **MxRL 2** Prototypical method concept is tested by the developers in a controlled or idealized scenario.
III	Validation	Iterative application, evaluation and optimization to validate methodical approach, tools and documentation under controlled conditions through1. Expert feedback2. Realistic scenario application by developers3. Guided third-party application (with support of developers)4. Independent third-party application (without support of developers)”	**MxRL 3** Methodical approach is conceptually optimized and validated on feedback of external experts. **MxRL 4** Methodical approach is optimized and validated on the basis of the application by the developers in realistic use cases (controlled conditions). **MxRL 5** Methodical approach is effectively utilized by trained third parties under controlled conditions, with developer support and supervision. **MxRL 6** Third parties successfully apply the methodical approach and achieve intended results without direct developer support, under controlled conditions.
IV	Transfer	Implementation concept, detailed documentation, traning and support structures are anchored in a real environment:1. Pilot application2. Roll-out3. Continuous application	**MxRL 7** Methodical approach is applied in a real-world pilot environment. **MxRL 8** Methodical approach is applied in multiple real-world environments beyond initial pilot applications. **MxRL 9** Methodical approach is widely adopted and established in practical applications.

mainly inspired by the TRL/MRL concepts (Holt et al., 2014; ISO 16290:2013) to structure readiness levels, the basic idea of the Validation Square (Pedersen et al., 2000) to conceptualize validation and the P4I approach (Köhler et al., 2021) to establish transfer.

The objective of the **initiation phase** is to recognize and document the problem and to work out the requirements for solution finding. This is a prerequisite for the start of a development process, but does not yet contribute to increasing the maturity of the development object. In order to be consistent with the naming of the following readiness levels, the term 'reaching MxRL 0' is therefore used here, even if strictly speaking it is not a readiness level. This step is crucial for developments within research projects, which require a thorough literature review. The need for method development can arise from various triggers, such as application problems with existing approaches, the need for adaptation, further development, or the necessity for a new approach.

The second phase involves the **conceptual development of the methodical approach**. This requires a sequence of iterative analysis and synthesis steps, which can vary in sequence and scope from case to case. However, sub-steps can be:

- the intensive analysis of the documented requirements
- analyzing an existing methodical approach, e.g. by observing and reflecting on its current application, procedures, and practices
- collecting and analyzing scientific findings or other sources of inspiration
- standardisation, i.e. the transfer of relevant content into a methodical approach concept

The result of this development process is initially a prototypical concept (MxRL 1). In its degree of maturity, this is to be understood as a hypothetical solution proposal, the functionality and applicability of which is still to be determined below. Therefore, the prototypical methodical concept developed must subsequently be applied to different cases and optimised. The progressive optimisation of functionality and applicability is also associated with an increase in the MxRL. In the logic of the proposed model, the initial testing of the methodical approach's concept is still part of the development phase. This represents the simulated application of the concept in a simulated, often ideal-typical test scenario by the developers. If the concept proves itself here, it reaches MxRL 2, which means that functionality has been demonstrated by the developers under controlled or idealized conditions.

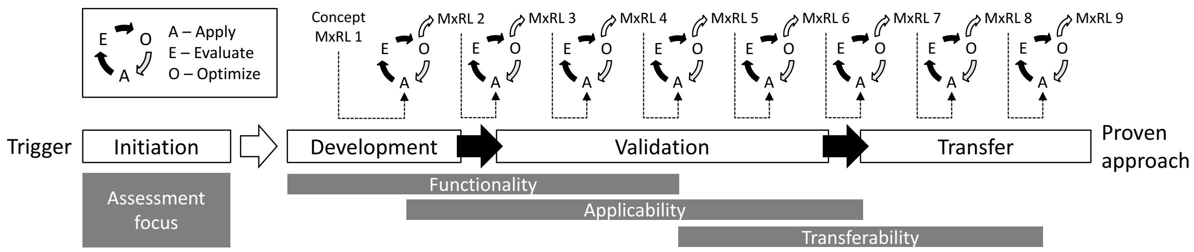

Figure 2. Micro-cycle of iterative optimisation of the MxRL

However, the level of maturity achieved in MxRL 2 is far from a methodical approach being functional in practice and being applicable in a targeted manner by users outside the development team (see Table 4). The maturity levels required for this are only achieved in the third phase for **validating the approach**. In this phase, the control level of the use case is gradually reduced until the approach is used independently in a final step. The logic of this phase always follows the iterative micro-cycle: application, evaluation and optimisation (Figure 2). This micro-cycle should be run through at each readiness level until there is no longer any significant need for change compared to the previous cycle. In principle, it is also conceivable that individual intermediate levels are skipped or integrated into higher readiness levels. In order to achieve MxRL 3, a conceptual optimization of the methodical approach's design with the inclusion of external perspectives is required. The result of the development phase should be discussed theoretically with experts (e.g. in the form of a qualitative interview) and appropriate feedback should be obtained, evaluated and, if necessary, incorporated. This step should precede the application of a methodical approach in particular because it is less time-consuming, can integrate additional practical knowledge and can also provide important information for the later practical tests. In order to achieve MxRL 4, the developers must prove that the developed approach functions on a real case study, but still under controlled (laboratory) conditions. However, its application at this readiness level is still carried out by the developers. Thus, the achievement of MxRL 4 represents an important step in the maturity increase: Here it has been shown that the methodical approach can be applied to real-world problems and that functionality therefore is given. To reach MxRL 5, on the other hand, it must be demonstrated that the method can be effectively applied to a real case by trained third parties with the support of the developers. At this readiness level, further findings can be gathered with regard to functionality. Essentially, this level aims to test, evaluate and optimise the applicability of the methodical approach by third parties. The developers train third parties to apply the approach to a suitable or selected real-life example, but actively intervene in the event of problems or ambiguities. In addition to the approach itself, first parts of the transfer concept (in particular training and training documents) must also be tested and evaluated at this level. For methodical approaches of MxRL 6, it has been demonstrated that they can be applied autonomously by trained third parties and lead to the intended results. The degree of control is only weak at this level: The functionality is still tested on a selected practical example, but the developers only observe the application for validation purposes and do no longer actively intervene in the application. When MxRL 6 is reached, the methodical approach is sufficiently validated in terms of functionality and applicability, thus, it has reached transfer maturity, including the training and its documents as well as the documentation of the methodical approach. This is the earliest stage at which a neutral comparison with a previous method can be meaningfully carried out for the entire method (e.g. A/B test).

Table 4. Development of functionality, applicability and transferability via the MxRL

MxRL	Functionality	Applicability	Transferability
0	Need / requirements	Need / requirements	/
1	Concept	Concept	/
2	Simulated	Idealized/highly controlled scneario by developers	/
3	Simulated with external experts	Highly controlled by developers	/
4	Tested & opitimized in realistic use case	Controlled by developers	/
5	Tested & opitimized in realistic use case	Controlled with developer support	Initial training material
6	Validated with realistic use case	Low control by trained third party	Training material, documentation (ready for transfer)
7	Real world	Low control	Transfer and support concept (pilot area)
8	Real world	Proven	Roll-out concept, beyond pilot area
9	Real world	Proven	Proven

The fourth phase of the generic process comprises the **transfer of the developed methodical approach**. This involves applying the method in a real environment. At MxRL 7, the successful application of the methodical approach in a pilot environment must be demonstrated. A pilot environment represents an initial controlled practical application, which is usually accompanied by method experts. A functioning transfer and support concept, e.g. by the developers, is therefore also necessary to achieve MxRL 7. Approaches at MxRL 8 have demonstrated their functionality and applicability in reality and have already been successfully applied outside pilot environments. There is therefore no longer any dependency on developers. The highest level of readiness (MxRL 9) is reserved for methodical approaches that have proven themselves many times over in practice. Based on these ten MxRL levels, methodical approaches can be developed, described, and analyzed. Although this approach is still in an early stage of development, it is evident that not all methodical approaches will be applicable to this framework.

4. Conclusion & outlook

This paper presents a novel approach for the maturity assessment in the development of engineering-related methodical approaches, aiming at enhancing transparency and comparability. The proposed solution not only supports developers and researchers in systematically designing methodical approaches but also incorporates readiness levels to offer a standardized assessment of their maturity in terms of functionality, applicability and transferability. By addressing the identified gap of comparability and transparency in existing processes, this contribution aims to provide a solution that bridges the gap between development practices and their evaluation.

The validation process demonstrated the approach's versatility and value. The retroactive application to existing methodologies revealed its utility in identifying gaps in and assigning maturity levels to methodical developments. Insights from expert interviews highlighted its practical benefits and relevance. Furthermore, the application to third-party development works, underscored the challenges posed by incomplete documentation in existing publications, reinforcing the necessity of a standardized and transparent process like the one proposed.

In a critical MxRL self-assessment, the approach described currently achieves MxRL 3, so it can be assumed that the approach still has potential for iterative optimisation. Nevertheless, the authors would like to make the MxRL concept available to the scientific and practical community and encourage them to try out the approach and provide feedback to the authors. This is essential in order to explore the limitations of the approach on a broad basis. The initial applications are promising, but it has been shown, for example, that each MxRL does not have to be run explicitly. However, it is still unclear, for example, in which cases this is the case. Future work should therefore focus on testing the approach in different academic and practical applications in order to determine the potential and limitations of the approach. By doing so, the precise field of application for the method can be defined and delineated. Collaboration with experts from various disciplines will be key in gathering this comprehensive feedback and improving the process. Additionally, iterative self-assessment will guide the approach's evolution towards higher maturity levels, ultimately contributing to its standardization and widespread adoption. By doing this, the presented solution might lever the potential to lay a strong foundation for advancing the methodological rigor and clarity in engineering research, fostering greater alignment between academic development and practical application.

References

Aguiar, M. F., & Jugend, D. (2022). Circular product design maturity matrix: A guideline to evaluate new product development in light of the circular economy transition. *Journal of Cleaner Production*, 365, 132732. https://doi.org/10.1016/j.jclepro.2022.132732

Blessing, L. T., & Chakrabarti, A. (2009). DRM, a Design Research Methodology (1st ed.). Springer London.

Boorsma, N., Polat, E., Bakker, C., Peck, D., & Balkenende, R. (2022). Development of the Circular Product Readiness Method in Circular Design. *Sustainability*, 14(15), 9288. https://doi.org/10.3390/su14159288

Buchner, G. A., Stepputat, K. J., Zimmermann, A. W., & Schomäcker, R. (2019). Specifying Technology Readiness Levels for the Chemical Industry. *Industrial & Engineering Chemistry Research*, 58(17), 6957-6969. https://doi.org/10.1021/acs.iecr.8b05693

Cupp, A., Fritts, A., Brey, M., Woodley, C., Smith, D., Cornish, M., McGovern, A., Simmonds, R., & Jackson, N. (2023). Application of the Technology Readiness Levels Framework to Natural Resource Management Tools. *Fisheries*, 48(11), 474-479. https://doi.org/10.1002/fsh.10982

Eisenbart, B., Blessing, L. T., & Cantamessa, M. (2024). Two decades apart and looking forward - exploring rigour in reporting on research in the engineering design research community. *Journal of Engineering Design*, 1-26. https://doi.org/10.1080/09544828.2024.2327912

Franke, H.-J., & Deimel, M. (2004). Selecting and combining methods for complex problem solving within the design process. In D. Marjanovic (Ed.), *Proceedings of DESIGN 2004, the 8th International Design Conference, Dubrovnik, Croatia* (DS 32, pp. 213-218).

García-Mireles, G. A., Moraga, M. Á., & Garcia, F. (2012). Development of Maturity Models: A Systematic Literature Review. In T. Baldassarre M. Genero, E. Mendes & M. Piattini (Eds.), *16th International Conference on Evaluation & Assessment in Software Engineering (EASE 2012): Proceedings* (pp. 279-283). IEEE. http://ieeexplore.ieee.org/servlet/opac?punumber=6262522

Gericke, K., Eckert, C., Campean, F., Clarkson, P. J., Flening, E., Isaksson, O., Kipouros, T., Kokkolaras, M., Köhler, C., Panarotto, M., & Wilmsen, M. (2020). Supporting designers: moving from method menagerie to method ecosystem. *Design Science*, 6. https://doi.org/10.1017/dsj.2020.21

Gökalp, M. O., Gökalp, E., Gökalp, S., & Koçyigit, A. (2023). The development of data analytics maturity assessment framework: DAMAF. *Journal of Software: Evolution and Process*, 35(8), Article e2415. https://doi.org/10.1002/smr.2415

Goldkuhl, G., & Karlsson, F. (2020). Method Engineering as Design Science. *Journal of the Association for Information Systems*, 21(5), 1237-1278. https://doi.org/10.17705/1jais.00636

Hecklau, F., Kidschun, F., Kohl, H., & Tominaj, S. (2020). Generic Process Model for the Structured Analysis of Methods: A Method Engineering Approach for the Analysis of RTO Capability Methodologies. In Au-Yong-Oliveira M. & Costa C. (Eds.), *Proceedings of the 19th European Conference on Research Methods, ECRM* 2020, 18-19 June 2020, hosted by The University of Aveiro, Portugal (pp. 106-114). Academic Conferences and Publishing Iinternational Limited.

Holt, J., Ingram, C., Larkham, A., Lloyd Stevens, R., Riddle, S., & Romanovsky, A. (2014). COMPASS Convergence Report 3 (D11.3). *UNEW.*

Ivanova, K. (2023). Multi-Method Framework for Development of Systemic, Technology-Driven Capability Concepts [Dissertation, UNSW Sydney]. *DataCite*.

Jagtap, S., Warell, A., Hiort, V., Motte, D., & Larsson, A. (2014). Design methods and factors influencing their uptake in product development companies: a review. In Marjanovic D., Storga M., Pavkovic N., & Bojcetic N. (Eds.), *Proceedings of the DESIGN 2014 13th International Design Conference* (DS 77, pp. 231-240).

Köhler, C., Luedeke, T. F., Conrad, J., & Grashiller, M. (2021). A PROPOSAL FOR METHOD TRANSFER BASED ON SUCCESSFUL EXAMPLES OF INTRA-INDUSTRY METHOD TRANSFER. *Proceedings of the Design Society*, 1, 181-190. https://doi.org/10.1017/pds.2021.19

Lame, G. (2019). Systematic Literature Reviews: An Introduction. *Proceedings of the Design Society: International Conference on Engineering Design*, 1(1), 1633-1642. https://doi.org/10.1017/dsi.2019.169

Mansfield, M. (2019). A Systematic Approach to Model-based Engineering of Cyber-Physical Systems of Systems [Dissertation]. *Newcastle University*. https://theses.ncl.ac.uk/jspui/handle/10443/4635

Pedersen, K., Emblemsvag, J., Bailey, R., Allen, J. K., & Mistree, F. (2000). Validating design methods & research: the validation square. *In Proceedings of DETC'00 - 2000 ASME Design Engineering Technical Conferences, Baltimore, Maryland* (pp. 1-13).

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A Design Science Research Methodology for Information Systems Research. *Journal of Management Information Systems*, 24 (3), 45-77.

Poorkiany, M., Johansson, J., & Elgh, F. (2016). Capturing, structuring and accessing design rationale in integrated product design and manufacturing processes. *Advanced Engineering Informatics*, 30(3), 522-536. https://doi.org/10.1016/j.aei.2016.06.004

Proenca, D. (2016). Methods and techniques for maturity assessment. *In 2016 11th Iberian Conference on Information Systems and Technologies (CISTI)* (pp. 1-4). IEEE. https://doi.org/10.1109/CISTI.2016.7521483

Rosemann, M., & Bruin, T. de (2005). Towards a Business Process Managment Maturity Model. *ECIS 2005 Proceedings*, 37. http://aisel.aisnet.org/ecis2005/37

Sadin, S. R., Povinelli, F. P., & Rosen, R. (1989). THE NASA TECHNOLOGY PUSH TOWARDS SPACE MISSION SYSTEMS. *Acta Astronautica* (20), 73-77.

Schneider, B., Alexander, J., & Thomas, P. (2023). NSB-2023-33, Publications Output: U.S. Trends and International Comparisons (SCIENCE & ENGINEERING INDICATORS 2024). *National Science Foundation, National Science Board, National Center for Science and Engineering Statistics*. https://ncses.nsf.gov/pubs/nsb202333

ISO 16290:2013. *Space engineering - Definition of the Technology Readiness Levels (TRLs) and their criteria of assessment*.

Wallace, K. (2011). Transferring Design Methods into Practice. In Birkhofer H. (Ed.), *The Future of Design Methodology* (pp. 239-248). Springer.

Wohlin, C. (2014). Guidelines for snowballing in systematic literature studies and a replication in software engineering. In Shepperd M., Hall T., & Myrtveit I. (Eds.), *Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering* (pp. 1-10). ACM. https://doi.org/10.1145/2601248.2601268