

Quantitative Evaluation of Assessment Items of the Technology Audit Method for Research and Technology Organisations (RTOs)

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Abstract: Applied research and development (R&D) organisations strive to develop technological solutions that translate results from research and science into state-of-the-art products and services. As advanced technological capability is essential to their competitiveness, they need to be able to analyse and evaluate their technological capabilities. Hence, a tool or method is required that objectively and practically assesses the technological capability of Research and Technology Organisations (RTOs) while meeting their unique requirements. The *technology audit* enables the assessment of the technological capability and thus the technological maturity of an RTO. It focuses on the analysis of the research activities in the R&D service areas of the RTO. This allows for a comprehensive understanding of the technologies used, the research competencies, the technologies developed, and the established technology partnerships of the RTO. In this context of the development of a suitable technology audit methodology, this paper aims to describe the process of validation of assessment items for evaluating the technological maturity of applied R&D organisations. After a brief overview of the technology audit method and the assessment dimensions and items, the focus is placed on the process of its validation. An expert survey using a questionnaire was created and used to evaluate the relevance of the 11 assessment items for the technology audit instrument in the three dimensions of *Technology Base, Products & Services* and *Cooperation*, as well as the respective aspects within each assessment item. This evaluation is intended to validate the selection of the items and to specify their respective importance to ultimately optimise the process of auditing applied R&D organisations.

Keywords: Assessment Dimensions & Items, Expert Survey, Technological Capability, Technological Resources, Technology Evaluation, Technology Audit

1. Introduction

Applied Research & Development (R&D) organisations aim to develop solutions that translate the results of research and science into advanced products and services. Since advanced technological capabilities are an essential requirement for their competitiveness, they must be able to analyse and evaluate their technological capabilities in a practical and objective manner. The *technology audit*, as described in this paper, provides an eligible methodology and approach for assessing the technological maturity of an applied R&D organisation and, more broadly, Research and Technology Organisations (RTOs) through a workshop process (Rubenstein and Geisler 1991; Porter 1978). To get a comprehensive understanding of the used technologies, research competences, developed technologies, as well as the established technological partnerships, the technology audit mainly focusses on the analysis of research work within the R&D service areas of the RTO.

Over a period of several years, the technology audit method has been developed, continuously updated and improved. The development of the method so far can be traced in the following publications, which deal in detail with a broad range of literature and expert discussions (Hecklau et al. 2019a; Hecklau et al. 2019b; Hecklau et al. 2019c; Hecklau et al. 2020a, 2020b, 2020c; Hecklau et al. 2022b).

To further optimise the technology audit method, the assessment items were evaluated. Within the framework of an expert survey by means of a questionnaire, the relevance of the 11 assessment items for the technology audit tool was assessed in the three dimensions of *Technology Base, Products & Services*, and *Cooperation*, as well as the respective aspects within each assessment item. This assessment is intended to validate the selection of the items.

To begin with, the technology audit method is explained below.

2. Technology Audit Method

The technology audit method allows analysis and evaluation of the technological performance and thus the technological maturity of an RTO. A standardised procedure is used for this purpose, for which various models such as the maturity model or the model of assessment dimensions are used, as well as tools and templates. This procedure enables a structured assessment of the RTO to be audited (Hecklau et al. 2022b).

The process consists of two main parts: the *technological maturity assessment* and the *technology dialogue*. The main session constitutes the technology audit workshop, which takes place in the process step of the technological maturity assessment. Using the assessment dimensions and items described in detail in Hecklau et al. 2022a, the RTO's technology maturity level is assessed in this step. Further steps include the *preparatory session* and the *final presentation and discussion of the auditor's assessment results*. The second and optional part of the *technology dialogue* is focused on a more extensive collaboration between the technology auditor and the organisation to be audited. For this purpose, e.g., mutual competence development is targeted based on the results of the technological maturity assessment. In principle, various activities are possible in this step, including those to initiate joint research activities, such as workshops with industry representatives or joint project acquisitions. In all steps, despite any further cooperation intended, the neutrality of the auditor has to be ensured (Hecklau et al. 2022b).

3. Assessment Dimensions & Assessment Items

For the technology audit, three main dimensions for technology assessment and the corresponding assessment items are defined. The assessment dimensions of the technology audit thus comprise the *Technology Base*, *Products & Services*, and *Cooperation* of the RTO. Within the assessment dimensions, further assessment items are defined. These concretise the respective dimension and enable a targeted evaluation within the scope of the technology audit. The assessment dimensions are shown in Figure 1.

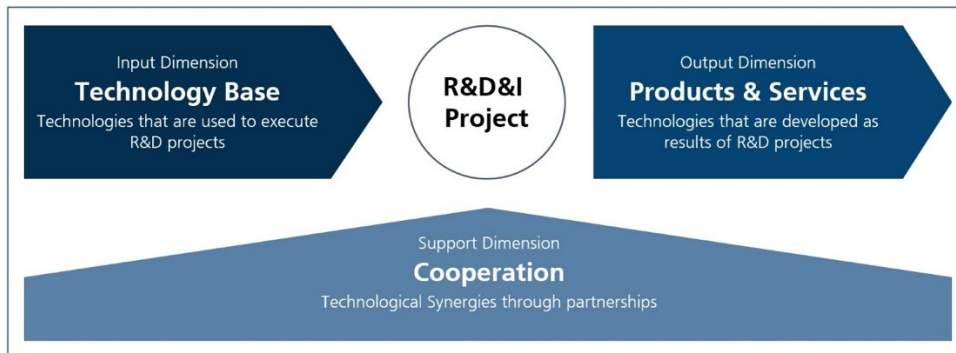


Figure 1: The 3 assessment dimensions of the technology audit

The *Technology Base* dimension focuses mainly on technologies and competencies of the RTO that are used to conduct research activities. Therefore, in line with the understanding of Technological Capability, it is also referred to as the *input dimension*. The guiding question for assessing this dimension can be formulated as follows: with the available technology base, is the RTO capable of performing state-of-the-art R&D activities in the defined technology and service areas?

Table 1 gives an overview of all assessment items of the assessment dimension *Technology Base*.

Table 1: Input Dimension: Technology Base

Input Dimension Technology Base Technologies that are used to execute R&D projects	
Technological Strategy <ul style="list-style-type: none"> • Technical Resource Planning • Human Resource Planning • Technology Benchmarking • Technology Foresight • Technology Roadmapping (external) • Awareness of new usable Technologies 	Technical Equipment / Software <ul style="list-style-type: none"> • General Equipment / Software • Specific Main Equipment / Software • Maintenance of Equipment / Software
Technical Infrastructure <ul style="list-style-type: none"> • Building(s) 	Competences <ul style="list-style-type: none"> • General Technical Competences • Specific Technical Competences • Core Competences • Formal Qualification of Staff

Input Dimension Technology Base Technologies that are used to execute R&D projects	
<ul style="list-style-type: none"> • Laboratories • Maintenance of Infrastructure • Accreditation 	<ul style="list-style-type: none"> • Competence Development / Training

Since the *Products & Services* dimension focuses mainly on the results of research, development and innovation activities and on the creation of innovative technical solutions, it can be referred to as the *output dimension*. The guiding question is as follows: By carrying out R&D activities in the defined R&D/services areas, does the RTO actually translate technologies into innovative solutions and products with clear benefits for industry?

Table 2 gives an overview of all assessment items of the assessment dimension *Products & Services*.

Table 2: Output Dimension: Products & Services

Output Dimension Products & Services Technologies that are developed as results of R&D projects	
Complexity of Research, Development and Innovation (R&D&I) Results <ul style="list-style-type: none"> • Market-Pull / Technology Push • Diversity of TRL • Multidisciplinarity • Project Volume • Run Time of the Project • Follow-Up Projects Innovative Technological Results <ul style="list-style-type: none"> • High Quality Products / Processes • High Quality Technical Services • Customised Technical Solutions • High-Quality Research Work • Technology Protection / IP 	New Technological Solutions as Products <ul style="list-style-type: none"> • Technology Trends • Technology Scouting • Technology Roadmapping (internal) • Potential Technology Spillovers

In the *Cooperation* dimension, the degree of integration of the RTO into the regional, national as well as international innovation ecosystem is analysed and evaluated. Synergistic technological collaboration helps the RTO to access complementary research competencies or partner technologies, equipment and infrastructures needed for the research work. Thus, this dimension can be referred to as the *support dimension*, which focuses on the following guiding question: Does the RTO actively engage in the innovation ecosystem and create strategic technological synergies with high-performing R&D partners to secure and expand its own field of activity?

Table 3 gives an overview of all assessment items of the assessment dimension *Cooperation*.

Table 3: Support Dimension: Cooperation

Support Dimension Cooperation Technological Synergies through partnerships	
Collaboration with Internal and External Research and Technology Organisations (RTOs) <ul style="list-style-type: none"> • Universities • Academies, Research Groups • RTOs (Research Institutes) Cooperation to Subcontractors / Third Parties <ul style="list-style-type: none"> • Integration & Usage of Technologies from Service Providers • Integration & Usage of Technologies from Customers 	Cooperation with Innovation Ecosystem <ul style="list-style-type: none"> • Start-Ups • Incubators • Accelerators • Science and Technology Parks Future Cooperation with National / International Partners <ul style="list-style-type: none"> • Partner Scouting • Competitor Analysis

The assessment items as well as the aspects and descriptions are described in detail in Hecklau et al. 2022a. Their selection is based on an extensive literature review that include the following sources: Garcia-Arreola 1996; Kaiser 2001; Hecklau et al. 2018; Phaal et al. 2004; Prahalad and Hamel 1990; Herstatt and Lettl 2001; Martinez-Vela 2016; Oberhagemann 2015; Sun and Fan 2016; Geisler 1999; Phaal et al. 2001; Kohl 2003; Coombs and Bierly 2006; Labuschagne and Brent 2006; Rush et al. 2007; Lau et al. 2010; Chen and Zhao 2012; Macchi and Fumagalli 2013; Liu and Jiang 2016; Chakravarty et al. 2013; Zhou et al. 2016; Gökalp et al. 2007; Ravichandran 2017; Lee et al. 2018; Salisu and Abu Bakar 2020; Wu et al. 2020; Hassan et al. 2021.

For the evaluation, a standardised technological maturity model is used, consisting of 5 different levels, starting with maturity level 1 – minimal technological maturity – and ending with the highest maturity level 5 – very high technological maturity. The purpose of the application of this model is to enable the most objective and standardised assessment result possible, allowing comparability across different RTOs. The technology maturity model is described in detail in Hecklau et al. 2022b.

The generic technological maturity model is visualised in the following figure.

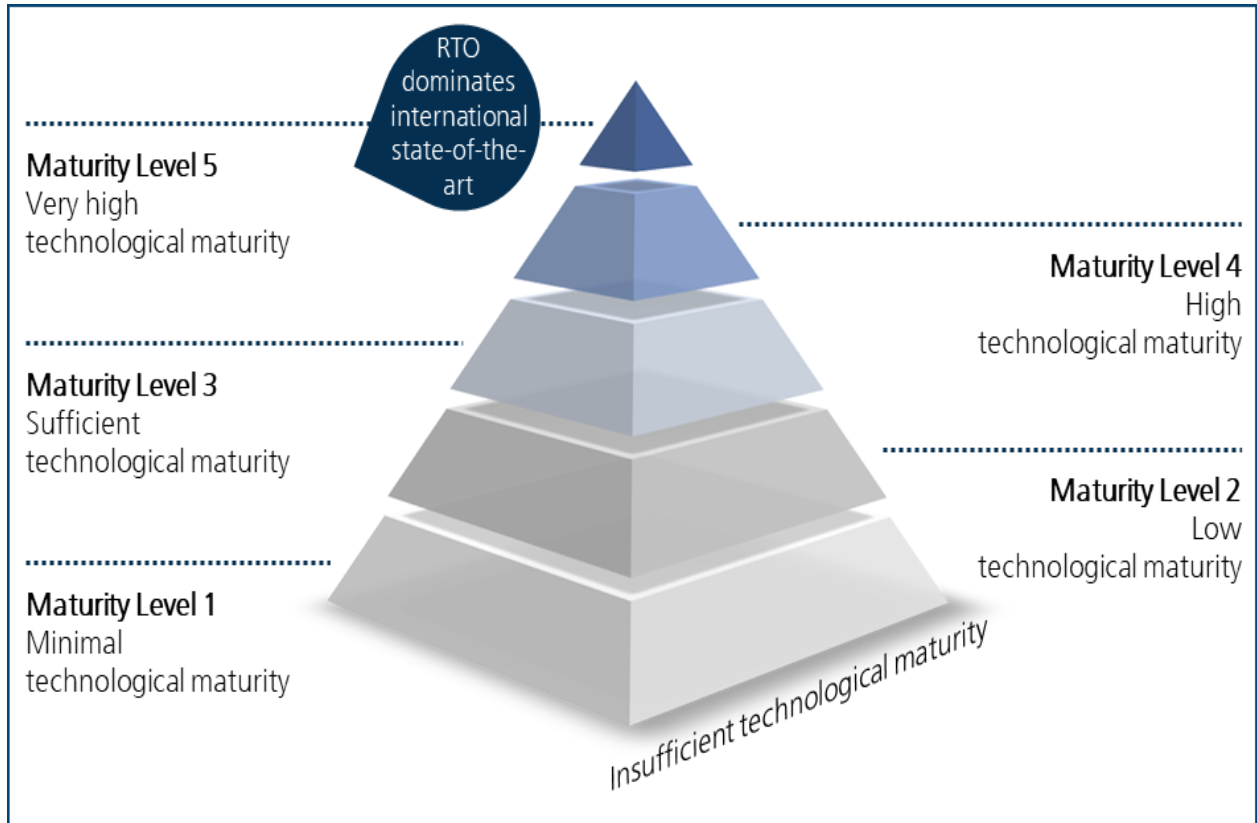


Figure 2: Technology maturity model

4. Validation of Assessment Dimensions & Assessment Items

For the quantitative evaluation of the technology audit method, a survey was created. Here, the relevance of the individual assessment items, as well as each individual aspect of the assessment items for the technology audit could be rated on a scale from 1 (very low relevance) to 5 (very high relevance). The goal was to remove assessment items with an average rating below 3 from the final set because their relevance was too low. All assessment items that were rated with at least 3 (medium relevance) by the experts were considered validated. The following expert groups were consulted:

- **13 method experts:** experts who have many years of experience, particularly in creating management methods and tools. These include experts from Fraunhofer IPK's Corporate Management department and experts from the headquarters of the SENAI network of 26 innovation institutes in Brazil.
- **11 application experts:** experts who have experience in applying management methods and tools. Experts from 8 different Fraunhofer institutes (IST, FOKUS, IGB, IPA, ICT, IZM, IML, IWU), who had applied the prototype of the technology audit in RTOs in Brazil, were surveyed.

4.1 Results of the expert survey

The detailed analysis of the expert survey shows that method and application experts rated the assessment items very similarly. The application experts who already have experience in using the prototype of the technology audit tended to rate the relevance of the assessment items somewhat lower.

Regarding the evaluation of the four assessment items of the dimension *Technology Base*, the item *Competences* was evaluated as the most important one. It is considered a very relevant element for the technology audit.

Technology Strategy was also rated similarly high. *Technical Infrastructure* and *Technical Equipment / Software* were rated less highly in comparison, but they still have a high relevance. The results of the expert survey in the *Technology Base* dimension are summarised in Figure 3.

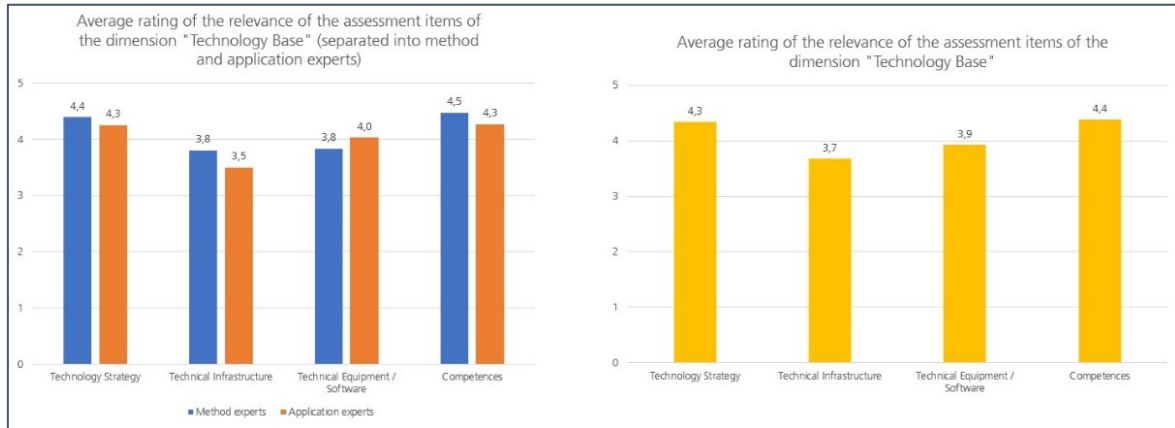


Figure 3: Results of the expert survey of the "Technology Base" dimension

In the *Products & Services* dimension, the item *Innovative Technological Results* in particular was rated high and thus as very relevant. In comparison, the assessment items *Complexity of R&D&I Results* and *New Technological Solutions as Products* were rated slightly lower, but well above the threshold of 3. The assessment results for the *Products & Services* dimension are shown in Figure 4 below.

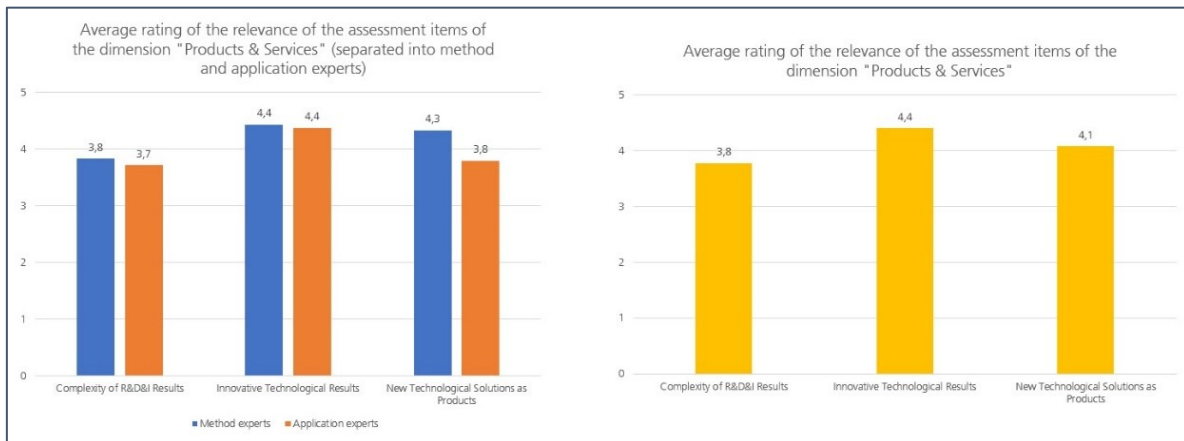


Figure 4: Results of the expert survey of the "Products & Services" dimension

The assessment items of the *Cooperation* dimension were rated lower on average and thus less relevant for consideration within the technology audit than the items of the other two dimensions. Only *Collaboration with Internal and External Research and Technology Organisations (RTOs)* was rated comparably high. *Cooperation to Subcontractors / Third Parties*, *Cooperation with Innovation Ecosystem*, and *Future Cooperation with National / International Partners* were rated lower, but above the threshold of 3 and are therefore also considered relevant for the technology audit. The expert survey results in the *Cooperation* dimension are compiled in Figure 5.

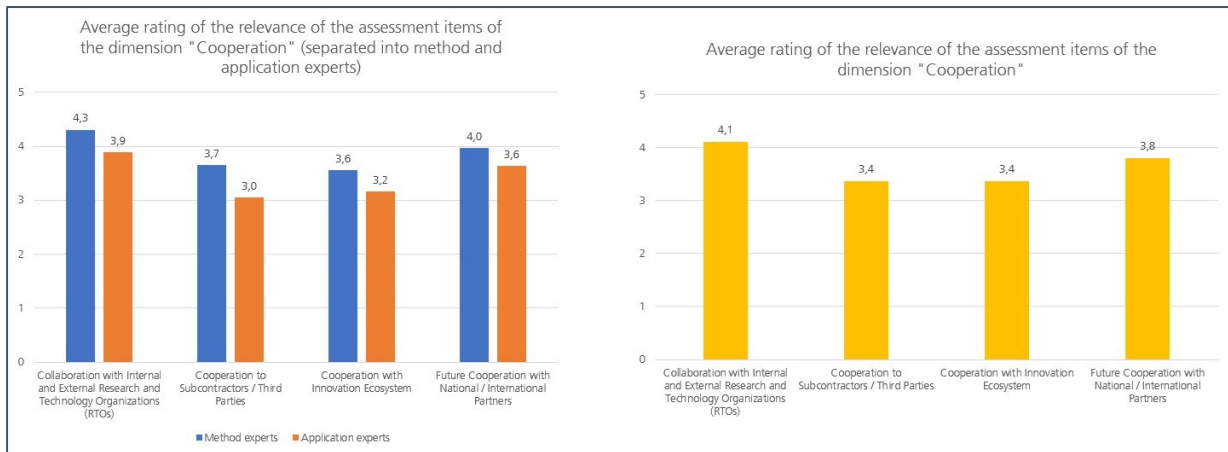


Figure 5: Results of the expert survey of the "Cooperation" dimension

The evaluation of the expert survey shows that all assessment items in the three assessment dimensions were rated by both groups of experts with at least 3 and thus as relevant for the technology audit tool. Accordingly, no assessment item was removed from the final set (short list). All eleven assessment items listed are thus considered validated.

The final set of eleven assessment items including all aspects in the three dimensions, which forms the basis for the auditor's evaluation of the RTO during the technology audit, is shown in Figure 6.

Input Dimension Technology Base Technologies that are used to execute R&D projects	Output Dimension Products & Services Technologies that are developed as results of R&D projects	Support Dimension Cooperation Technological Synergies through partnerships
<p>Technological Strategy</p> <ul style="list-style-type: none"> • Technical Resource Planning • Human Resource Planning • Technology Benchmarking • Technology Foresight • Technology Roadmapping (external) • Awareness of new usable Technologies <p>Technical Infrastructure</p> <ul style="list-style-type: none"> • Building(s) • Laboratories • Maintenance of Infrastructure • Accreditation <p>Technical Equipment / Software</p> <ul style="list-style-type: none"> • General Equipment / Software • Specific Main Equipment / Software • Maintenance of Equipment / Software <p>Competences</p> <ul style="list-style-type: none"> • General Technical Competences • Specific Technical Competences • Core Competences • Formal Qualification of Staff • Competence Development / Training 	<p>Complexity of R&D&I Results</p> <ul style="list-style-type: none"> • Market-Pull / Technology Push • Diversity of TRL • Multidisciplinarity • Project Volume • Run Time of the Project • Follow-Up Projects <p>Innovative Technological Results</p> <ul style="list-style-type: none"> • High Quality Products / Processes • High Quality Technical Services • Customized Technical Solutions • High-Quality Research Work • Technology Protection / IP <p>New Technological Solutions as Products</p> <ul style="list-style-type: none"> • Technology Trends • Technology Scouting • Technology Roadmapping (internal) • Potential Technology Spillovers 	<p>Collaboration with Internal and External Research and Technology Organizations (RTOs)</p> <ul style="list-style-type: none"> • Universities • Academies, Research Groups • RTOs (Research Institutes) <p>Cooperation to Subcontractors / Third Parties</p> <ul style="list-style-type: none"> • Integration & Usage of Technologies from Service Providers <p>Cooperation with Innovation Ecosystem</p> <ul style="list-style-type: none"> • Integration & Usage of Technologies from Customers <p>Future Cooperation with National / International Partners</p> <ul style="list-style-type: none"> • Start-Ups • Incubators • Accelerators • Science and Technology Parks • Partner Scouting • Competitor Analysis

Figure 6: Validated list of assessment items including sub-aspects of the technology audit

The three highest rated aspects from this validated list, which therefore deserve special emphasis, are *Core Competences* (4.7), *Human Resource Planning* (4.5), and *Collaboration with RTOs* (4.4). The technological *Core Competences* represent bundles of technologies and capabilities with a concrete application reference (e.g. set of technological business areas) which, detached from concrete product and market constellations, lead to a decisive competitive advantage through superior customer benefits (RTO's unique selling proposition basis). Core competences should be valuable, rare, difficult for competitors to imitate and not substitutable by other competences. *Human resource planning* includes effective attraction, recruitment, continuous human resource development and retention management within the RTO. The aspect *Collaboration with RTOs* includes the provision of complementary joint research results and the development of high-level innovative solutions through synergistic collaboration with other Research and Technology Organisations.

5. Summary & Outlook

The assessment dimensions, their items and respective aspects form the central categories of the technology audit. Therefore, their selection is of integral importance for the audit method. The quantitative analysis, in

which 13 method experts and 11 application experts were interviewed using a questionnaire, confirmed this selection of 11 assessment items.

The method evaluation was carried out with the aim of validating and, if necessary, optimising the method. Even though some of the items were considered more significant than others, all items were rated as relevant by the 24 experts who participated in the validation process. Based on this finding that the assessment items are consistently highly important, all assessment items could be validated. Accordingly, there is no need to adjust the set of items. The technology audit method should therefore continue to evaluate RTOs on their performance in these categories to ensure a comprehensive evaluation.

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