INESC TEC Scientific Advisory Board Visit Report

Contents

1. Introduction

Per the INESC TEC Statutes, the external monitoring, guidance, and evaluation of scientific activities shall be carried out by the Scientific Advisory Board (SAB) which shall regularly assess INESC TEC's overall operations and issue an opinion on INESC TEC's activity plans and activity reports. To fulfill its responsibility, the SAB conducted a review visit on May 11 & 12, 2023 to INESC TEC Porto, Portugal. This report summarizes the SAB's findings and recommendations from said visit.

The INESC TEC Scientific Advisor Board (SAB) is composed of:

Dr. José Fortes (Chair)	University of Florida, USA.
Dr. Elsa Angelini	Telecom Paris, France.
Dr. Anne-Marie Kermarrec	EPFL - Ecole Polytechnique Fédérale de Lausanne, Switzerland.
Dr. Masaru Kitsuregawa	National Institute of Informatics, Japan.
Dr. Edward Knightly	Rice University, USA.
Dr. Robert Lieberman	Lumoptix LLC, USA.
Dr. Mario Paolone	EPFL - Ecole Polytechnique Fédérale de Lausanne, Switzerland.
Dr. Tomás Gómez S. Román	Universidad Pontificia Comillas, Spain.
Dr. Bruno Siciliano	Università degli Studi di Napoli Federico II, Italy.
Dr. M. Grazia Speranza	Università degli Studi di Brescia, Italy.
Dr. Volker Stich	Aachen University of Technology, Germany.

All but Dr. M. Grazia Speranza and Dr. Bruno Siciliano participated in the visit due to scheduling conflicts. Dr. Elsa Angelini, Dr. Anne-Marie Kermarrec and Dr. Masaru Kitsuregawa only attended parts of the visit remotely for unavoidable reasons.

All the SAB members who participated in the visit contributed to this report.

This report is divided into four major parts:

1. Context and objectives of the visit.
2. Key findings and recommendations to the Board of Directors.
3. Reports on individual scientific domains of INESC TEC.

2. Context and Objectives of the INESC TEC Site Visit

INESC TEC is a dynamic institution described in its Activity Plan 2021 as "*a private, non-profit association dedicated to scientific research and technological development, technology transfer, advanced consulting and training, and pre-incubation of new technology-based companies.*" Since the last SAB visit in November of 2021, INESC TEC has developed a strategic plan for 2023-2030, defining its vision and mission as "*To be inspiring and empowering force, driving the science and technology of digitally-enabled systems into overcoming society's challenges*", and "*As a free-thinking and diverse community, we take on bold science, technology, and innovation challenges, empowering talent, collaborative ecosystems, and public policies that make a difference in our economy and society*", respectively.

The primary focus of the SAB visit was to provide feedback on scientific research activities while secondarily considering the other INESC TEC activities which interplay with scientific work in the context of its 2023-2030 strategic plan. During the first day of the two-day visit, six parallel sessions provided information on INESC TEC activities in six scientific domains, namely: Bioengineering (BIO), Communications (COM), Computer Science & Engineering (CSE), Photonics (PHT), Power and Energy Systems (PES), and Systems Engineering & Management (SEM). Reviews of the Artificial Intelligence (AI) and Robotics (ROB) domains were deferred to a later date. During the first day, plenary single-session presentations were also made on trans-domain (also known as transversal) projects and on INESC TEC as an organization. During the second day of the visit, the SAB visited INESC TEC laboratories and presented its preliminary findings to the INESC TEC Board of Directors and INESC TEC researchers.

INESC TEC provided to the SAB the following documents prior to the visit:

- Slides of all presentations
- INESC TEC Strategic plan 2023-2030
- Gender Equality Plan 2022-2026
- SAB Meeting agenda

The SAB members held several meetings among themselves, contributed thoughts and text, and reviewed drafts of this report. This report presents the final version of the SAB's key findings and recommendations, responses to questions asked by the Board of Directors (BoD), and feedback on the activities of each scientific domain. The final contents of this report have been reviewed and are agreed to by all the SAB members who participated in the visit.

3. Findings and Recommendations to the Board of Directors

3.1 Key Findings

3.1.1 Summary Assessment

The SAB reiterates its largely positive evaluation of INESC TEC from the last SAB review in 2021. Citing from the last visit report, the following observations remain true:

- "The SAB is impressed by INESC TEC's large scale, healthy financial condition, privileged geo-economic position and high performance for several metrics."
- "INESC TEC is unique (in a good way) because its activities occur at all TRL levels, reflecting and enabling the translation of scientific discoveries into prototypes, products and services that are used by industry or originate start-ups, ultimately having a positive economic impact."
- "There is strong evidence of impactful INESC TEC contributions at all levels: academic, technology transfer, economic and public good."
- "INESC TEC's timely interdisciplinary projects clearly illustrate the benefits of its profile and differentiate it from organizations that are mostly academic or mostly technological."

Updates from the SAB on the above-listed findings are provided below, supplementing previous SAB recommendations. Also included are commentaries on observed improvements, some of which reflect SAB recommendations after its 2021 review visit.

3.1.2 Excellent Overall State of INESC TEC

The overall funding of INESC TEC activities has consistently increased from just under 19 M Euros in 2018 to approximately 25.5 M Euros in 2022. A significant part of this growth resulted from increases in funded European Programmes. This trend improves the financial robustness of INESC TEC by reducing its historically large percentual dependence on national funding. It is also an indicator of the recognition of INESC TEC researchers as desirable European project leaders and collaborators. The combination of multiplicity and diversity of INESC TEC funding sources is a differentiating strength of the institution.

For R&D-specific funding, the portion from National Programmes decreased since 2021, reflecting the overall decrease of public R&D funding in Portugal. This is compensated by increases in R&D funding from European Programmes and PhD grants, resulting into a near-constant level of R&D funding since 2018 (~10 M Euros).

3.1.3 Unique Successful INESC TEC Profile

INESC TEC's ability to attract and conduct R&D work at all TRL levels continues to be one of its distinguishing characteristics and one of the reasons why INESC TEC funding model is resilient. This unique characteristic is a competitive advantage for INESC TEC science which should be further leveraged. Several projects demonstrate that INESC TEC can carry out work that starts at low TRL levels where new science is created and continues to higher TRL levels where technology and product development take place. This Science-to-Technology-to-Society (STS) continuum reflects INESC TEC's vision "...driving the science and technology of digitally enabled systems into overcoming society's challenges." Furthermore, as mentioned in the last SAB report, INESC TEC has created an environment where "scientific domains and technology platforms (the so-called TEC4s) provide bidirectional pathways between science contributions and technology innovations in support of market and societal needs". The SAB notes that INESC TEC's STS culture and practices are increasingly visible across the institution.

3.1.4 Impactful INESC TEC Contributions

One of the strengths of INESC TEC research is its societal relevancy. There is a strong connection between projects and society, by INESC TEC being responsive to urgent society needs in a timely manner and aiming to serve society in the long run. Another strength of INESC TEC research is its boldness. All presented cross-domain projects have compelling goals with societal impact and individual domains include projects at the leading edge of science.

INESC TEC's number of annual scientific publications since 2018 oscillates between 897 and 968, of which more than half are journal papers in 2022. Researchers are highly visible internationally through 185 international collaborations, editorial responsibilities and organizational leadership roles in many hundreds of journals and conferences. These publications and activities quantify an impressive level of both scientific and service impacts.

Additionally, INESC TEC's research has produced 152 software tools and 123 datasets and has led to 35 granted patents. These outcomes are tied to tools and data relevant to science, technologies and products with socio-economic impact.

Finally, several projects and activities exemplify INESC TEC's capacity to translate scientific knowledge into innovative technologies and engineering solutions to social problems. Exemplary projects include STAYAWAY Covid contact tracing algorithm, PS-MORA software tool for large scale renewable energy integration planning, Deep Brain Stimulation implantable and wearable devices for Parkinson's Disease and Epilepsy, digital twinning tools for IKEA factory design and autonomous underwater robotics development. Exemplary activities include INESC TEC's involvement in the creation of the Agency for Integrated Rural Fire Management (AGIF) and the ForestWISE CoLAB.

3.1.5 Unique Timely Interdisciplinary Projects

The SAB is positively impressed by the nature and number of "transversal" projects and activities, i.e., projects that involve investigators and knowledge from several domains. The eight projects and activities presented during the visit showcase the unique INESC TEC capabilities to lead or participate in European or National scale initiatives. They also illustrate the STS profile of INESC TEC at work. Collectively, they impact many aspects of society, including sustainable energy production and management (EU-SCORES and InterConnect), health (Health from Portugal), smart industry (Produtech R3), earth sensing (NEWSAT), fire prevention and fighting (FIRE RES), underwater communications (GROW), and smart agriculture (SCORPION).

3.1.6 Academic Levels of Scientific Productivity

From the data presented to the SAB in the welcome presentation, approximately 5 papers are published annually per faculty member. This compares well with many engineering departments of leading international universities whose faculty members are mostly dedicated to scientific research. However, many INESC TEC faculty members (who are also academics) additionally contribute to technology and its deployment while achieving scientific publications production comparable to pure academics.

3.1.7 Actions on SAB Recommendations from the 2021 Visit

INESC TEC has started to follow up on most of the SAB's recommendations from the 2021 visit, namely:

- *Improving Identification and Description of Strategic Objectives*

  INESC TEC produced a Strategic Plan for 2023-2030. The long-term nature of the plan, the description of the vision, mission and values of INESC TEC, the strategic core objectives along with key performance indicators (KPIs) and targets, and the specification of initiatives and programmes to be implemented are all very good.

- *Improving Scientific Production*

  INESC TEC has identified four initiatives (two of which have already been started) which are positive steps towards increased scientific production: (1) internal seed funding for high-risk/high-reward projects, (2) international visiting researchers' program, (3) promotion of publications in highly ranked journals and (4) increase in PhD students enrolment. These initiatives are likely to increase the quantity and quality of technical products and reinforce the institutional practice of high-quality scientific publications. Some of these initiatives will take time to yield results so KPI metrics should be used to track progress and identify what does or does not work, including the possibility of other types of initiatives.

  There are promising data regarding scientific publication production. The average total number of publications in the period 2018-2022 is 918, with a consistent annual increase in journal publications; there is a decrease in the number of conference publications, possibly reflecting COVID pandemic impacts on reduced travel and conference events.

- *Grow Competencies Strategically*

  INESC TEC is starting to address this recommendation in a holistic manner, taking into consideration not only the need to eliminate gaps in expertise but also the need for clear career paths, workforce diversity, retention and other aspects of sound human resource management. This has the potential to bring systemic improvements of human capacity at INESC TEC, particularly if the need for competencies is correctly anticipated.

Equity and inclusion have also been addressed in an impressive comprehensive assessment and planning document (Gender Equality Plan 2022-2026) with actionable initiatives to increase gender equity, some of which are already under way. The SAB noticed a significant increase of participation (including as speakers) by women and young researchers in this visit when compared to the 2021 visit.

- *Seek to Establish Scientific Breakthroughs*

  INESC TEC has started to create the organizational and infrastructure conditions to address this recommendation. The SAB agrees that the clustering of INESC TEC competencies into scientific domains brings out the existence of a critical mass to tackle important scientific problems, as well as the viability of interdisciplinary work needed by grand societal challenges. Similarly, investments in infrastructures developments are essential to translate scientific breakthroughs into realistic scenarios at the right scale.

3.2 Key Recommendations to the Board of Directors

3.2.1 Further Initiatives Addressing SAB's 2021 Visit Recommendations

The SAB recommends INESC TEC to continue and expand its initiatives to address the recommendations from the 2021 SAB visit regarding their fundamental nature and long-term impacts. Desirably, more existing (or new) metrics should be used to quantify and track progress as much as possible so that necessary adjustments can be made.

3.2.2 Identification and Comparison of Peer Institutions with INESC TEC

This recommendation from the SAB's 2021 visit remains unaddressed. This is a very important recommendation, and it has the most potential to impact every aspect of the scientific enterprise at INESC TEC. Among other benefits, it will provide clear benchmarks for performance, bring out any resource limitations, contrast domain expertise and human resources, reveal funding models impacts and needs, and expose operational strategies. Additionally, peer benchmarking can serve as yardsticks by which the INESC TEC BoD can measure its effectiveness, in a way that is credible for external evaluations.

3.2.3 Institutionalization and Highlighting of STS culture

The unique STS nature of many INESC TEC's projects should be embraced as a part of the INESC TEC scientific culture. Clearly, as already mentioned, several INESC TEC projects have already demonstrated the existence and value of this STS culture. However, there appears to be a perception (external and/or internal) that STS activities are not good for science, which is not necessarily the case. To counteract this perception, INESC TEC needs to "institutionalize" the extraction of research questions from projects that include development of technologies, products, or services. Likewise, anticipated practical impacts should be identified for projects focused on scientific questions. These bi-directional dynamics, i.e. Science-to-Technology-to-Society and Society-to-Technology-to-Science (also captured by the STS acronym being a palindrome) should be adopted as best practices for INESC TEC projects, done throughout the conceptualization and span of every project. The expected cumulative outcome would be a consistent perception (by internal and external entities) of valuable synergistic contributions to science, technology, and society by INESC TEC. The impacts of STS activities on society often take much longer to show up, in comparison with technical outcomes such as papers. INESC TEC should set up metrics and mechanisms to track STS outcomes over long periods of time past the actual duration of projects. Common metrics and impact tracking mechanisms should be consistently used for all STS projects. INESC TEC is well positioned to establish such best practices as it has had several successful STS-like projects in the past with long term impact which can be used as case studies.

3.2.4 Better SWOT Analysis and Action Plans

Domain-level SWOT analysis needs to be done more carefully and frequently (e.g., not only for site visit reviews), avoiding situations where analysis content is rushed just prior to a deadline. It should also be accompanied by an action plan on how to address the issues revealed by the SWOT analysis. Such a document can inform on institution-level planning, support domain-level communication and support shared actions. It can also be used to seek focused feedback from the SAB and other external evaluators or advisors.

3.2.5 Strengthen the Strengths

INESC TEC's domain-level visions are not uniformly compelling. INESC TEC and its different domains need to consider what the realistic "next level" is and what is needed to "jump to the next level". This prevents complacency and losing existing strengths to competitors or changing timelines. It also creates the proper mindset for SWOT analysis reviews and corresponding amendments to action plans and visions.

4. Feedback on Individual Scientific Domains

4.1 Bioengineering (BIO)

4.1.1 Competencies

4.1.1.1 Summary assessment

The presentation reports 15 fields of competencies, which cover a very large scope of data types, medical application domains, stakeholders, and technological domains. The BIO domain has rightfully identified as a critical challenge the enforcement of strong synergy and the identification of syncretic forces that will define the DNA of INESC-TEC BIO activities.

4.1.1.2 Feedback on strengths

The 15 fields of competencies are at the scale of a large US-based BME Department, which is impressive. Thanks to this diversity of fields, the BIO domain has a huge potential to engage in large-scale ambitious projects addressing important and unmet "health challenges" going across scales and across technologies.

The reporting mentioned a large pool of PhD students with ongoing research topics in relation with the BIO domain, as well has a higher average H-index within the domain than across INESC-TEC which are both very positive assets.

Part of the strength is this pool of PhD students, who play key roles in establishing solid collaborations with stakeholders (e.g., data providers, test-bed environments, international visibility via Challenge participations)

4.1.1.3 Feedback on weaknesses

Given the very large scope of the domain, leadership and steering comes with higher challenges. A dual leadership might be considered, with regular rotations so that all fields get some visibility and steering opportunities. It might also be important to provide leadership opportunities to young and mid-career researchers, especially in emerging fields.

There might be a need to clarify the medical applications targeted in the mentioned "biometrics" field, as it is not clearly illustrated and comes with potential high risk of ethical approvals by not only regulatory bodies but also the general public.

The BIO domain might also consider clarifying its extension to environmental data and its link to the transversal project FIRE-RES.

4.1.2 Vision

4.1.2.1 Summary assessment

The vision of the BIO domain is presented in very broad terms but defines well the field of bioengineering. The mentioned application domains cover a large scope (diagnosis, ageing, rehabilitation, computational biology, environmental sciences) and four goals, including fostering synergy and "enabling the innovation and technology transfer with economic impact".

4.1.2.2 Feedback on strengths

The large scope of competencies and past success in patent filing and spin-off establishments support the displayed ambition of the BIO domain to "enabling innovation and technology transfer with economic impact". The BIO domain seems to have identified a good strategy for building synergy: mandatory attendance of regular scientific meetups, and of "show & tell" meetings on cross-domain topics.

The definition of the goals seems to have gone through a survey of the INESC-TEC BIO community, which is very positive.

4.1.2.3 Feedback on weaknesses

Such a large scope of envisioned applications might come with some risk in terms of lack of focus, lack of cross-data or technologies fertilization, and dilution of efforts leading to diminished impact.

The BIO domain might consider rewording its visions in terms of building some synergy for general cross-applications topics such as diagnostic tools, SI support, treatment & rehabilitation devices, epidemiology methodologies.

Some key research domains are not mentioned in the provided Vision, which could be considered such as: drug design, AI for health, or digital twins for medicine.

Regarding the BIO domain synergy, it seems essential to raise awareness of the BIO domain within INESC-TEC, especially toward the PhD students community. Leaders of the BIO domain could consider raising money from local sources, such as corporate sponsors willing to get access to graduate students or the IEEE EMBS local chapter, to support the organization of small gathering events for PhD students. The loss of a gathering space for students was mentioned and seems detrimental to structuring this community.

4.1.3 Projects

4.1.3.1 Summary assessment

Five key projects were presented, with again a large scope of data types and application domains.

4.1.3.2 Feedback on strengths

The BIO Domain reports several EU funded projects which is very positive. These EU projects enable INESC-TEC to collaborate with high-quality international collaborators (including US institutions such as Carnegie Mellon University).

The presented projects address ambitious topics with high potential impact and transfer potentials, such as genomic data information representation and visualization (Inno4Vac**),** and multi-applications AI-based explainable tools (TAMI).

The presented projects involve some big EU-based pharmaceutical companies as collaborators (e.g. GSK, Sanofi).

The NanoSTIMAR RL1 project brings some clear potentials to be used internally as best practice of a successful spin-off story in terms of building a Business Model, prototyping on diverse technologies (nano-scale cell optical monitoring and manipulation, in-silico ECG sensor, risk-management of failures of medical devices) and engagement of collaborators and supporters.

The development of qualitative measures for AI explainability is very interesting and should be pursued as early as possible with clinical collaborators.

4.1.3.3 Feedback on weaknesses

The BIO domain could improve its projects' presentations regarding the objectives in terms of deliverables (e.g. new algorithms, software tools versus hardware sensors), and targeted level of use-case evaluation within the scope of a project.

The 15 listed fields of expertise are not clearly linked with the 5 presented projects.

Some projects' presentations were not clear on data access readiness and onsite support for resolving data access agreements (e.g., TAMI project).

Some discussions raised potential issues on staying up to date on the sensors technology used in some projects.

Early strategical thinking on valorizing the outcomes of the presented projects could also have been presented.

4.1.4 Assets

4.1.4.1 Summary assessment

Elements listed to evaluate the assests of the BIO domain included selected publications, PhD dissertations, patents, awards and spin-offs.

4.1.4.2 Feedback on strengths

Some publications appear in high-rank venues (Nature Machine Intelligence, MICCAI Conference, IEE TMI,...).

It is very good to see emerging hot topics such as federated learning involved in a current PhD dissertation.

Several recent patents are listed but lack some information on proportion of ownership by INESC-TEC.

Three spin-offs are mentioned, with different levels of maturity, which is very positive.

4.1.4.3 Feedback on weaknesses

Some selected publications are of lower quality in terms of venue rank.

Ongoing PhD dissertations seem to be dominated by data science projects, and do not seem to cover all the listed 15 fields of competencies.

4.1.5 Challenges

4.1.5.1 Summary assessment

Four Research Challenges (RCs) were presented:

1. From Macro-to-Nano Scale Biosensing
2. Novel Technologies for Personalized Health & Wellness
3. New Challenges in Medical Signal & Image Analysis
4. BioRobotics & Human-Machine Symbiosis

4.1.5.2 Feedback on strengths

There are clear potentials for cross-fertilization between challenges.

There are clear potentials to develop AI tools for niche data sensors (e.g. white-light imaging)

4.1.5.3 Feedback on weaknesses

Challenges could be formulated more specifically as challenges rather than domains of research (in particular for RC3).

The scope within RC1 seems quite broad in terms of sensors types, which could be a risk.

The presentation of some Challenges lacked clearly identified clinical partners and data providers (e.g., national hospitals). This is particularly important for projects related to AI but also for the Challenge 4, on how Robotics will enter the surgery field.

Regarding the use of AI for health data, there might be a need to clarify how the proposed methods will aim for "multimodal and holistic approaches". The BIO domain leaders in AI should also position their research with respect to the very strong international competition.

4.1.6 Recommendations

The presentation seems to confirm that the BIO domain has the right critical mass.

In biomedical engineering research, we face specific challenges when setting up a new project in terms of formulating clearly "what is the added value" and for which stakeholder(s). The BIO domain seems to be well-aware of common barriers to technological innovations raised by clinical end-users when facing potential disruptions of their routine practice. This is why it is important to engage very early in a project some clinical/industrial champions who will support/acquire the technology. It is also important to share best practices within the BIO Domain, via for example a shared repository of funded proposals, or a mentoring process for preparing grant submissions.

The SWOT analysis reports strong structural strengths and opportunities to pursue, such as the Asprela campus as a Biomedical campus and ongoing efforts to develop opportunities with private clinical institutions.

4.2 Communication Systems (COM)

4.2.1 Competencies

4.2.1.1 Summary assessment

Stated competencies are diverse and comprehensive. (Communications architectures and protocols, Electronics, Multimedia, Network and resource management Network security, Optoelectronics and photonics, Reconfigurable hardware systems, Signal processing, System modelling, simulation, and prototyping, Wireless communications).

4.2.1.2 Feedback on strengths

Competencies address fundamentals and have wide breadth, yielding an excellent foundation for embarking on large impactful projects.

4.2.1.3 Feedback on weaknesses

None noted, but strengthening quantum communications expertise should be encouraged.

4.2.2 Vision

4.2.2.1 Summary assessment

The vision statement (Context-aware, on-demand communications systems using and providing ubiquitous sensing) is broad, forward looking, and well-timed for next generation communications such as 6G and Wi-Fi 8.

4.2.2.2 Feedback on strengths

The vision provides an excellent connection of sensing and localization to broader problems. Moreover, it leverages past successes and is sufficiently specific that it is actionable.

4.2.2.3 Feedback on weaknesses

"On demand" is a valuable network feature. Yet, to better match with newer projects such as Converge, it can be expanded or rephrased, e.g., dynamic or real-time. The past vs. future vision can be further investigated.

4.2.3 Projects

4.2.3.1 Summary assessment

New projects include the CONVERGE project to fuse computer vision and communications, the Terrameta project which targets reconfigurable intelligent surfaces, the FLEXCOMM project which targets energy aware communications, and the TORIS project which targets printed reconfigurable intelligent surfaces.

4.2.3.2 Feedback on strengths

Ending projects were outstanding and culminated in world-leading experimental demonstrations. Emerging projects are also excellent and have synergy among them due to having overlapping foundations. TERRAMETA has a strong vision of the software-defined factory leveraging mobile robots, sensing, and THz networks. The scope spans from fundamentals such as THz channel models to RIS design and future standards. CONVERGE is an outstanding project with potential for high impact on 6G. Researchers and student presenters are highly knowledgeable in their areas and are well trained.

4.2.3.3 Feedback on weaknesses

The COM domain could present more explicitly how projects synergistically fit together both in time and on topics.

4.2.4 Assets

4.2.4.1 Summary assessment:

Publications are in high quality venues including IEEE Access, IEEE IoT Journal, IEEE/ACM Transactions on Networking, and IEEE Communications Magazine. Patents and collaborations are strong.

4.2.4.2 Feedback on strengths:

The journal publication record is extensive and an excellent indication of quality work. PhD production appears to be ramping up, which is of high importance.

4.2.4.3 Feedback on weaknesses:

Conference papers, workshop papers, and demo sessions can be leveraged to further expose the work. Researchers could target awards for recognition of the best results.

4.2.5 Challenges

4.2.5.1 Summary assessment:

The three identified technical challenges are: Autonomous Communications Systems, Communications for Extreme Environments, and Obstacle-aware Communications. The challenges were well defined and were also broken down to sub-challenges and their interactions were well thought out. Moreover, they are actionable.

4.2.5.2 Feedback on strengths:

The selected challenges are forward looking and have potential for high impact.

4.2.5.3 Feedback on weaknesses:

The challenge names can be broadened to reflect their breadth as they go well beyond what the names suggest. Some sub-challenges can be applied to multiple main challenges, so their connections can be better identified.

4.2.6 Recommendations

The COM domain could make explicit connections between the core scientific problems, technical contributions, and broader societal impact.

The COM domain should develop an “award” culture to better recognize and publicize researchers and their accomplishments. Increased researcher and project recognition and awards can begin internally, e.g., “best thesis award” within a domain. Multiple experimental projects would be strong contenders for “best demo award” in conferences and workshops.

The vision and challenges of the COM domain are strong but can be rephrased to better reflect new projects such as CONVERGE.

While past experimental demonstrations were world-class and leading, further investment is needed in experimental facilities to realize the forward-looking research vision and plan.

For SWOT analysis, the COM domain can add a strength of taking on big and bold problems with potential for high societal impact.

4.3 Computer Science and Engineering (CSE)

4.3.1 Competencies

4.3.1.1 Summary assessment

- The scientific domain has a "very good coverage" of the area, referring to the fact that they are involved in 20 areas that cover half of the SIG (Special Interest Group) in ACM. The domain is actively conducting research, development, and innovation in various subfields or topics and makes significant contributions to these areas.
- There is a concern over the fact that AI is considered "another scientific domain." Indeed, AI is one of the most important research areas within computer science and engineering and it might be relevant to recognize AI as an integral part of the CSE domain rather than being seen as an independent scientific domain.

4.3.1.2 Feedback on strengths

- Scale of a large department: he CSE domain is a sizable academic or research institution with a considerable number of faculty members, researchers, and staff and has the resources and infrastructure to support extensive research and educational activities.
- Some very strong areas: Within the CSE domain, there are specific areas of research or expertise that stand out as particularly strong with a high level of specialization, depth of knowledge, and notable achievements offering a competitive advantage or expertise in those specific fields, attracting researchers, students, and collaborations in those areas.
- High-profile researchers: The domain comprises renowned scholars and experts within its faculty and research staff. These researchers have made significant contributions to their respective fields, gained recognition from the academic community, and have a strong reputation. High-profile researchers enhance the CSE domain prestige and can attract collaborations, funding opportunities, and talented individuals to INESC TEC.
- Large pool of PhD students: There is a substantial number of PhD students, demonstrating that the domain is actively involved in education, nurturing

and training the next generation of researchers, contributing to the advancement of knowledge in their respective fields. A large PhD student population can facilitate a vibrant research environment, knowledge exchange, and collaboration within the CSE domain.

Collectively, these points demonstrate that the CSE domain is of a significant size, strong expertise in specific areas, hosts renowned researchers, and a thriving research community comprising a large number of PhD students. These attributes indicate a dynamic and productive academic institution with a robust research culture and the potential for impactful contributions to CSE.

4.3.1.3 Feedback on weaknesses

No specific weakness is noted apart from the concern of excluding AI from the CSE domain.

4.3.2 Vision

4.3.2.1 Summary assessment

The presented vision highlights the importance of addressing key characteristics of computing systems in the context of ongoing digital transformation namely scalability, security, correctness, interoperability and efficiency required for sustainable digital systems.

4.3.2.2 Feedback on strengths

The CSE domain encompasses various subfields, disciplines, or aspects related to computing systems relevant to a wide range of applications, technologies, and research areas within the domain. The characteristics mentioned (scalability, security, correctness, interoperability, and efficiency) are common denominators to many fields. This implies that these characteristics are fundamental and widely recognized as essential components of successful computing systems across different areas within the domain.

4.3.2.3 Feedback on weaknesses

- Lack of emphasis on synergies between areas: One potential weakness is the ability to adequately address the synergies between different areas within the domain. Focusing on the individual strengths of each area without considering how they can integrate and collaborate may lead to missed opportunities for innovation and holistic advancements.
- Inadequate inclusion of AI in the domain.

4.3.3 Projects

4.3.3.1 Summary assessment

There is a wide variety of projects within the CSE domain, covering many different areas, indicating a rich and diverse research and development landscape. (even if none of these projects were presented in the meeting)

4.3.3.2 Feedback on strengths

The strength lies in the success of certain projects in terms of publications, specifically highlighting areas such as distributed systems, hardware, and high-performance computing (HPC). These projects have achieved notable publications, indicating a strong research output and contribution to the scientific community.

There are also a number of high-impact projects typically making significant advancements, innovations, or breakthroughs in their respective fields, leading to substantial contributions and recognition within the scientific community and beyond.

This demonstrates the ability of the researchers involved to generate novel insights, advance knowledge, and address important challenges within the CSE domain. Such successful projects can enhance the reputation and visibility of the institution or individuals involved, attracting further collaborations, funding opportunities, and talented researchers and students.

4.3.3.3 Feedback on weaknesses

One potential weakness is that projects can exhibit significant differences in terms of funding, output, and impact. This variability can pose challenges in assessing the overall effectiveness and success of projects. The impact of projects, which may include societal, economic, or environmental footprints, can also differ greatly. This variability makes it difficult to compare and evaluate projects objectively and may hinder the efficient allocation of resources.

A second comment is on the lack of information on transfer and spin-offs/startups: This is not so much a weakness but there has been a lack of available information regarding the transfer of knowledge or the creation of spin-off companies or startups resulting from the projects.

4.3.4 Assets

4.3.4.1 Summary assessment

The elements listed for summary included selected publications, PhD dissertations, patents, and awards.

4.3.4.2 Feedback on strengths

One strength is the presence of publications in high-ranking venues. This indicates that the research conducted by the team has been recognized and accepted by prestigious journals or conferences in their respective fields, demonstrating the quality and significance of the researchers' work, enhancing their reputation and contributing to the advancement of knowledge in the academic community.

Another strength is the presence of a large team comprising highly qualified researchers, many of whom have completed or are pursuing PhD theses. The involvement of PhD candidates indicates a commitment to cultivating and nurturing talents, which can contribute to a productive research environment and the potential for long-term success.

The CSE domain has an impressive publication record, particularly in the selected publications. This indicates a consistent ability to produce high-quality research outputs, enhancing their credibility to attract collaborators and funding, and establish themselves as leaders in their research areas.

The CSE domain has an impressive list of international collaborations. Collaborating with researchers from different countries and institutions promotes knowledge exchange, fosters innovation, and expands access to diverse perspectives and resources. International collaborations can lead to more comprehensive research outcomes, increased visibility, and potential opportunities for joint projects, funding, and sharing of best practices.

Overall, these strengths reflect the CSE domain's strong academic standing, research capabilities, and potential for producing impactful outcomes in terms of publications, collaborations, and expertise development.

4.3.4.3 Feedback on weaknesses

The CSE domain's performance in generating patents appears to be relatively low considering its size.

There is a lack of available information regarding the impact on industry transfer or the creation of startups.

Software production is not highlighted enough: Although it is believed that the CSE domain engages in software production, this aspect is not emphasized or clearly highlighted.

4.3.5 Challenges

4.3.5.1 Summary assessment

Five Research Challenges (RCs) were presented:

1. Advancing the Software Development Ecosystem
2. Ensuring Software Correctness
3. Managing the Increasing Complexity of Critical Information Systems
4. Designing and Deploying Heterogeneous Computing Architectures
5. Improving Computational Systems for a better Human-Technology Symbiosis

4.3.5.2 Feedback on strengths

- Relevant and varied challenges: The CSE domain focuses on addressing relevant challenges, both long-term and shorter-term, showcasing its adaptability and alignment with industry needs.
- Exploration of new areas: The CSE domain actively explores exciting new areas, like quantum computing, demonstrating its commitment to staying at the forefront of advancements in its field.

4.3.5.3 Feedback on weaknesses

- The CSE domain could benefit from defining more concrete goals for the data research area. Having specific and well-defined objectives would provide clarity and direction, ensuring that research efforts are focused and purposeful.
- It is unclear to what extent the CSE domain’s various research areas embrace and adopt the identified challenges
- Some challenges, particularly the first one, heavily rely on datasets that may be difficult to acquire. Considering alternative approaches or diversifying data sources could mitigate this risk.
- While AI/ML is a natural fit for several challenges, such as Challenges 3 and 4, it is hardly mentioned. Highlighting the potential applications of AI/ML within these challenges could unlock opportunities for innovative solutions and maximize the CSE domain’s impact in these areas.
- There is no clear positioning of the identified challenges with respect to the international landscape. Understanding how the challenges compare or contribute to existing research efforts globally would provide valuable context and enable collaboration and benchmarking against international standards.
- Sustainability is not prominently addressed in the identified challenges, despite its importance, particularly for Challenges 3 and 4.

4.3.6 Recommendations

- It is recommended to include a more prominent focus on AI in the challenges, especially considering the potential impact it can have in various areas, such as Challenges 3 and 4. Exploring AI applications like federated learning, hardware platforms, and software correctness could provide innovative solutions and enhance the CSE domain’s research outcomes.
- Given the increasing importance of sustainability, it is recommended to explicitly include sustainability considerations within the challenges.
- To better position the CSE domain in the international landscape, it is advisable to provide clearer communication regarding the vision and research directions. Articulating the unique contributions and differentiators of the CSE domain’s work in relation to international counterparts will facilitate collaborations, benchmarking, and recognition on a global scale.
- The CSE domain is encouraged to emphasize (scientific) success stories, software tools, etc.

4.4 Photonics (PHT)

4.4.1 Competencies

4.4.1.1 Summary assessment

The PHT domain competencies span a wide range, including:

- Fiber Optic Sensors
- Fiber lasers
- Spectroscopic remote sensing, *in situ* sensing, and *in vivo* sensing
- Optical microfabrication of waveguides, resonant structures, and fluidic structures
- Metallic and dielectric nanostructures
- Optoelectronic signal processing
- Nonlinear optics
- Quantum simulations and optical computing
- Optical trapping/"tweezers"

The underlined competencies above are particular strengths, internationally recognized as being on a par with research at other world-class institutions.

4.4.1.2 Feedback on strengths

- Core competencies within the photonics domain encompass many scientific and engineering subfields, and have synergies with almost all other domains at INESC TEC.
- A good mix of mature research threads (fiber sensors, remote spectroscopy, …) with promising new thrusts (quantum simulations, microfabrication, …) should – with proper support – lead to continuing recognition of INESC TEC as a scientific leader in this domain.
- The PHT domain produces work at the boundaries of optical science, while at the same time being truly engaged in creating new "enabling technology" that leads to solutions of a variety of important problems.

4.4.1.3 Feedback on weaknesses

- The Advanced Photonics Center is a key resource for the PHT domain, but photonics/optics-related competencies in other centers at INESC TEC should be recognized as part of this domain.
- This domain seems under-staffed, given its critical importance to many activities at INESC TEC.
- Photonics-related equipment and facilities at INESC TEC are extensive but could in some cases benefit from modernization.

4.4.2 Vision

4.4.2.1 Summary assessment

The PHT domain's stated vision is appropriate, though rather generic:

- Advancing fundamental understanding of the physics of light-matter interactions.
- Developing and applying new sensing and information technologies based on this understanding.
- Fostering interdisciplinary collaborations identify and solve complex problems.
- Promoting sustainable development and advancing diversity and inclusion.

4.4.2.2 Feedback on strengths

- The PHT domain vision encompasses both basic and applied research.
- The emphasis on interdisciplinarity is particularly important.

4.4.2.3 Feedback on weaknesses

- A *specific* vision is missing (i.e., "In 10 years, the photonics domain will have done/ be doing…")

4.4.3 Projects

4.4.3.1 Summary assessment

- All of the many projects being caried out in the PHT domain, ranging from the most basic to the most applied are impactful and appropriate.
- Projects that may have the best "wow factor" when presenting the activities of the PHT domain to those not intimately familiar with optics and photonics include:
  - **Lira** –Micro-Kelvin temperature stability, possibly world-beating, for space applications;
  - **MODAS** – Ability to detect/predict earthquakes (and other events) by repurposing existing communication infrastructure;
  - **LightBrain** – Cutting-edge research on optical computing and simulation of quantum systems.

4.4.3.2 Feedback on strengths

- Tremendous versatility in fiber optic sensor development and applications; well-regarded by peers in groups around the world.
- Well-developed ability to use light to "machine" structures in glass.
- Growing portfolio of advanced spectroscopic acquisition and analysis techniques.

4.4.3.3 Feedback on weaknesses

- "Shyness:" Some researchers in the PHT domain seem to be reticent to emphasize the uniqueness and excellence ("wow factor") of their work and achievements.
- Project selection seems (in part) to be "what we could get funded."

4.4.4 Assets

4.4.4.1 Summary assessment

- Excellent production of publications, conference presentations, PhD dissertations, patents, and spin-offs.

4.4.4.2 Feedback on strengths

- Many publications in top-level journals.
- Participation in leadership (and even hosting) of important international conferences/symposia.
- Federated learning involved in a current PhD dissertation.
- Continuous "pipeline" of spinoffs, several successfully returning royalties to INESC TEC.

4.4.4.3 Feedback on weaknesses

- Some of the most important breakthroughs remain unknown to the rest of the world. Publication and dissemination of these breakthroughs must be done.
- The number of PhD students is small – may negatively impact the long-term creation of new science.

4.4.5 Challenges

4.4.5.1 Summary assessment

- Research Challenges addressed:
  - Photonic-based platforms for environmental monitoring, medical diagnostic and industrial applications.
  - Photonic sensing for extreme environments.
  - Optical systems and devices for analog quantum simulations.

4.4.5.2 Feedback on strengths

- Excellent coupling of research challenges with important scientific and societal problems.
- Good team-oriented approach to meeting challenges.
- Continuing dedication to solving the "hard problems," and following up with concrete technological results.
- Wide range of tools available, and applied, to address challenges.

4.4.5.3 Feedback on weaknesses

- Challenges need to be selected based on “where we want to go”

4.4.6 Recommendations

- Convene an “optics/photonics day” where INESC TEC researchers who use or develop technologies in this domain (e.g., cameras, optical fibers, lasers, image/spectral processing software, LIDAR, etc.) gather to discuss common issues.
- Highlight key “world’s best” and “world’s only” results in publications and conferences.
- Continue and expand participation in, and leadership of, international professional/industrial societies and organizations (EPIC, Optica, SPIE, IEEE, and stand-alone conferences like EWOFS, OFS, Europt(rode), ASCOS…).

4.5 Power and Energy Systems (PES)

4.5.1 Competencies

4.5.1.1 Summary assessment

- The competencies cover a wide spectrum of power system applications: operation and control, markets, power electronics, distributed energy resources, and micro-grids.
- They are extended to multi-energy systems and cyber-physical systems.
- As we noticed the inclusion of energy resources and technologies, we encourage to extend this domain with respect to fundamental science from materials to devices.
- Analytical methods include optimization techniques, data science, and reliability analysis.

4.5.1.2 Feedback on strengths

- Multidisciplinary approach dealing with complex energy systems.
- Modeling and simulation from large systems to micro-grids with a view on system integration.
- Extension to new relevant issues for decarbonization and digitalization: sector coupling and cyber-physical infrastructures.

4.5.1.3 Feedback on weaknesses

- The list of competencies is an unstructured catalog of areas, methods, and true competencies. We suggest restructuring it and aligning the competencies with the scientific challenges.

- The differences in excellence and maturity should be highlighted by putting forward the unique competencies of the domain.
- The contributions from different centers inside INESC TEC should be shown as a strength of the multidisciplinary approach.

4.5.2 Vision

4.5.2.1 Summary assessment

- Supporting the energy transition, decarbonization policies to be implemented around the world, and, in particular, in the EU.
- Scientific contributions in modeling and optimizing energy systems.
- Impact for the society, the industry, and governments on new concepts, models, methodologies and tools for decision-making.

4.5.2.2 Feedback on strengths

- The vision of decarbonization and digitalization of energy systems is well formulated, highlighting the scientific excellence of INESC TEC and the major pursued societal and industrial impacts.

4.5.2.3 Feedback on weaknesses

- In the stakeholders, we have not seen the presence of technology providers.
- The presentation and formulation of the vision should make more emphasis on both scientific excellence and societal, industrial, and policy impacts.

4.5.3 Projects

4.5.3.1 Summary assessment

- The selected set of projects spans a broad range of scientific and technical challenges (e.g., from low-voltage grids situational awareness coupled with distributed controls to system-level reliability and decision).
- The projects are well aligned with national and international (specifically EU) scientific and technical challenges.

4.5.3.2 Feedback on strengths

- The number of granted projects is impressive and leverages well established competences within the PES domain.
- Several developments (especially in the domain of optimal power systems planning, control and reliability assessment) rely on advanced state-of-the-art methods.
- The leadership of the PES domain is clear and well recognized and seems to positively influence members of this domain to think beyond their comfort zone.

- We also noticed the large number of young research fellows demonstrating the attractiveness of the granted projects.

4.5.3.3 Feedback on weaknesses

- Common denominator of projects' descriptions: researchers tend to describe what the project does, but they do not discuss which fundamental research question(s) the project addresses, why it is relevant for the scientific community and what is the scientific excellence of the projects' outcomes and their broad impact (industry, society, government).
- We also noticed that the projects were presented in a sequential and un-clustered way.

4.5.4 Assets

4.5.4.1 Summary assessment

- Similarly to the analysis on the projects, the selected set of publications has a large breadth and 1:1 maps the projects outcomes.
- Publications appear to be relevant to address mainstream scientific and technical challenges in the PES domain.
- Too much attention is put in quantifying the volume versus the excellence of the publications. We suggest showcasing a restricted list of the most scientifically relevant publications, patents and software tools.

4.5.4.2 Feedback on strengths

- Large network of international collaborations.
- Commitment to international Work Groups of IEEE, Cigré and IEA.

4.5.4.3 Feedback on weaknesses

- It is difficult to quantify the scientific throughput of the PES domain versus peers. We suggest including a performance assessment leveraging a comprehensive bibliometric analysis complemented by the identification of the most scientifically-influential publications.
- We suggest presenting the PES domain researchers in a structured way, identifying clear clusters per sub-area.
- Regarding datasets and software tools, we suggest indicating their users and if they are adopted to carry research beyond the INESC TEC perimeter. We also suggest describing their uniqueness versus what is made available by the international PES community and the industry (for instance, we noticed that some software tools refer to standard power systems analysis).

4.5.5 Challenges

4.5.5.1 Summary assessment

There are four challenges that cover the vision in line with the competencies:

1. decarbonization and digitalization of energy systems,
2. de-centralized business models and markets,
3. resilience and reliability, and
4. control architectures and centers.

4.5.5.2 Feedback on strengths

- The problems and needs that require new solutions are well formulated.

4.5.5.3 Feedback on weaknesses

- The presentation fails on selecting a few relevant scientific contributions per challenge, presenting a storyline about how the tracked scientific record is dealing with that, and the expected impact it will have in the next years.
- It is relevant to show in those cases, the connection between the challenge, involved competencies, selected projects, and obtained scientific results (publications, PhD theses, …).
- In the Challenge related to decarbonization of energy systems, the decision to develop the ammonia path is missing carbon capture, utilization and sequestration technologies, and we encourage to explore this path.
- In the Challenge related to control architectures and centers, the methodological contributions related to the definition of the control methods from event knowledge and users' behaviors were unclear.

4.5.6 Recommendations

- The SWOT analysis mentions the "high-capacity to anticipate industry needs": this is a statement that may negatively influence the scientific relevance of the results. Temptation to go with "risk-free" incremental research is an issue since it may influence the scientific growth ambition of INESC TEC.
- We suggest expanding the PES domain by including a sub-area on materials and devices for energy.
- We appreciate the idea of including datasets and software tools in the assets. However, to increase visibility of the obtained results, we recommend considering joining open-source platforms at EU level that make available these assets to a larger set of stakeholders.
- A clear career path for INESC TEC researchers should be clearly defined even by considering the coupling with the academic path with FEUP.

4.6 Systems Engineering and Manufacturing (SEM)

4.6.1 Competencies

The following competencies were discussed deeply:

- Industrial Information Systems: Data and Information Management, Digital Enterprise Architecture, Industrial Information Systems design

- Management Science: Operations Research, Operations Management, Advanced analytics, decision Sciences
- Service Science: Service System Design and Innovation, Service System Transformation
- Technology and innovation Management: Technology Management and Policy, Innovation Management, Technology based entrepreneurship.
- Cross cutting Competencies: Human-centered approaches, responsible research and innovation

The SEM domain should consider the increasing influence of platform-based services, and the new scientific questions to be explored like service sales engineering with the question of customers value creation or subscription business modelling with questions about service pricing of digital products.

The SEM domain needs to deeper understand and explore the new digitally driven human-centered approaches. The Digital Transition has three main impacts on:

- o Design of digital processes: which processes should be digitized or not?
- o Need of qualification description for new or now digitized (i.e. automated) tasks.
- o New forms of learning and qualification by using new technologies, (e.g., augmented reality and digital classrooms).

4.6.1.1 Summary assessment

The SEM domain has a long tradition in an area where it is hard to find really innovative “nuggets “. But in the actual context of global digital transformation, there is a big opportunity to put in an “Innovation Nail” when the SEM domain really focuses its existing competencies on the following:

- Understanding of digital processes and their potentials for new businesses.
- Considers the relevance of platforms and the potential of the platform economy.
- New approaches on how to change traditional culture patterns into the digital tomorrow.
- New forms of learning and qualification by using new technologies (e.g., augmented reality, digital classrooms).

4.6.1.2 Feedback on strengths

The SEM domain is close to industrial needs and has the knowledge to solve scientifically based problems. The domain is not forced to fund itself through consultancy for projects and business. It can therefore re-think in detail basic solutions for different stakeholders in different business areas like industry, health, logistics or farming.

4.6.1.3 Feedback on weaknesses

The SEM domain should be aware of numerous risks in being too generic or too broad regarding the various competencies. Being focused is key for being successful, convincing, and quick in problem solving. The research groups should not only focus on issues close to production. The near future will show the need to be able to transfer any suitable Information Systems Design approaches into other areas like Smart health, Smart Farming, Smart Building and Smart Mobility.

4.6.2 Vision

The SEM domain presented its vision as: "Systems engineering and management research seeks to advance the design, implementation and improvement of systems for decision support, Human-centered operations, intelligence technology management and innovation."

4.6.2.1 Summary assessment

The SEM domain has the potential to position itself as an interface between business needs and today's management challenges especially through the organizational aspects. Nevertheless, the SEM domain should rethink whether it is helpful to address a bit more the idea of scientifically paving the ground for the strongly needed DIGITAL TRANSITION IN INDUSTRY and nearby domains like Smart Health, Smart Building and Smart Farming.

4.6.2.2 Feedback on strengths

The vision is very well formulated and seems to be the result of an intensive and cooperative approach to cover the broad SEM area. Now the next step should be to rethink the vision's explanation "…Major challenges arise from optimization….". A good vision is understandable with one sentence that clarifies, what the research teams are going after or what they will provide to "which partner".

4.6.2.3 Feedback on weaknesses

We would have expected to find the intention of "Business transition into the digital future" in the vision, which is core (e.g., "we are paving the floor for digital transition of companies to stay competitive in a more digitized economy of tomorrow.")

4.6.3 Projects

4.6.3.1 Summary assessment

The following projects were presented in a detailed and very professional manner. The discussion with the experts showed a deep understanding and high engagement in the projects' goals:

- Transitioning socio-technical systems towards sustainability
    - Projects: POCITYF, EVERY1
- Developing responsive and resilient end-to-end value chains
    - Projects: SoTecIn Factory, BeFresh, ReSCape

- Managing Systems under uncertain, complex and dynamic environments
  - Projects: PRODUTECH R3, MAGPIE
- Engineering Human-centered systems for sustainability and resilience
  - Projects: CIRC THREADS, TRANSFORMER 4.0, OPTI-MOVES

4.6.3.2 Feedback on strengths

All presented projects (see above) are well structured and forward looking. The shown projects could gain high impact on the different fields of work for SEM. The presentation of the transversal projects shows the high impact of SEM, as 6 out of the presented 8 Projects got input from the SEM Domain.

4.6.3.3 Feedback on weaknesses

The broad variety of the SEM domain projects and the different targeted research issues may result in losing “power” by focusing on very specific single points of competencies. We would encourage the SEM domain in total to strengthen any project definition on the following questions:

- What is <u>THE</u> (scientific) problem and who is the recipient of any possible result or solution?
- How do you intend to solve the scientifically based problems?
- What are the expected results (software tools, methodology, standards, …)?

4.6.4 <u>Assets</u>

4.6.4.1 Summary assessment

The lists of publications and ongoing PhDs are impressive and cover the broad variety of the SEM domain competencies in an international environment.

4.6.4.2 Feedback on strengths

International collaborations should be mentioned to underline the SEM domain relevance. Awards listed underline the high quality of the work.

4.6.4.3 Feedback on weaknesses

Publication of methods or tools developed by the SEM domain could be strengthened to underline its deep competence and to help the next generation to stay in a constant line of research activities.

4.6.5 <u>Challenges</u>

4.6.5.1 Summary assessment

Four challenges were presented:

1. Transitioning socio-technical systems towards sustainability:
2. Developing responsive and resilient end-to-end value chains:
3. Managing Systems under uncertain, complex and dynamic environments:
4. Engineering Human-centered systems for sustainability and resilience:

Challenge 1: This challenge needs to be more deeply explored concerning the idea and meaning of "sustainability", which is key. The research teams could lay a profound basis in the form of a SUSTAINABILITY FRAMEWORK and its meaning in the context of Socio-technical systems. This framework gives the SEM domain a unique selling point and helps to make "sustainability tangible".

Challenge 2: When the research teams talk about responsiveness and resiliency they should be very clear about a framework or model that clarifies these two points and their relation to logistics or end-to-end value chains. It is crucial to avoid being misunderstood and to avoid using generic expressions without content. What should be highlighted, based on the profound expertise of these teams is the influence of digital technologies, that facilitate new opportunities in terms of transparency, real time tracking and tracing or even lifetime recognition of products. A big opportunity for these teams could be, to now revisit their way of thinking about the scientific challenges of today and ask questions for sustainability like:

1. Returning products;
2. Remanufacturing of products;
3. Reassembling and reusability of products.

to support the long-time use of products and to avoid the approach "waste after first use". Related Projects: SoTecIn Factory, BeFresh, ReSCape

Challenge 3: The challenge is well described. We recommend, concerning the research questions, that the teams very clearly differentiate between scientific questions (Point 1-5) and use-case driven questions (Point 6-8). The Point 1 and Point 6 research questions seem to be key for all further developments of the teams. The SEM domain should clarify internally whether it could be a good idea to develop something like a model or framework, which could be used by the whole group as a guideline for further developments and positioning internally and externally. Related Projects: PRODUTECH R3, MAGPIE.

Challenge 4: The teams have been well established for a long time. The same question is raised again: why are they taking into account "Sustainability and Resilience" and what are their meaning for human-centered systems? Overall, the teams are perfectly prepared for taking over a significant role in positioning and explaining what are the key challenges for new technologies and their role for the future of Digital Transition. The SEM domain now should rethink deeply about the need for a technical-organizational framework on Enterprise Architecture, as the design of a digital, agile and adaptive company requires an optimal business-IT alignment as well as strategic alignment with corporate IT. A research question to be touched upon in the future could be: "How can digital technologies be selected and used in a benefit-oriented and targeted manner in order to increase the efficiency and effectiveness of business processes, product and business model development?" Related projects: CIRC THREADS, TRANSFORMER 4.0, OPTI-MOVES.

4.6.5.2 Feedback on strengths

All presented challenges (see above) are well structured and forward looking, the shown projects could have high impact.

4.6.5.3 Feedback on weaknesses

The broad variety of challenges and adherent project may result in losing "power" on specialization on some single points of interest, and care should be taken for holding the broad variety together.

4.6.6 Recommendations

The SEM domain should consider more:

- International positions and publications of similar working groups (i.e. ACATEC Study of Global Scs https://www.fir.rwth-aachen.de/en/research/production-management/supply-chain-management/)
- Put more efforts on (international) benchmarking:
"Where are possible partners already experienced in SEMs original "challenges" (i.e. Technical Services, New business modeling, Industry 4.0 or Digital Transition)
- Focus on its internal knowledge management and not forget what SEM had already achieved years ago!

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6. Signature Page

The Scientific Board Members

Dr. José Fortes (Chair) ________________________________ Date _______

Dr. Elsa Angelini ________________________________ Date _______

Dr. Anne-Marie Kermarrec ________________________________ Date _______

Dr. Masaru Kitsuregawa ________________________________ Date _______

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