Exploring Transformation in and Across Clusters of Excellence

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Abstract At the RWTH Aachen University, there are two Clusters of Excellence: The Fuel Science Centre (FSC) and the Internet of Production (IoP). Due to their complex structures, long-term funding, broad variety of disciplines involved and other exclusive characteristics, they provide high chances of change and might, thus, be seen as levers for transformation. In this article, the focus is put on the potential transformation on the content-level and the structures as well as the implications of transformation on the team and work processes are described since the Clusters of Excellence do not only underlie external influences fostering transformation (e.g. political decisions or environmental conditions) but also internal ones due to, for instance, staff turnover or new research findings influencing the future visions and operating of the clusters.

Keywords Cluster of Excellence · Transformation · Fuel Science Centre · Internet of Production

1 Introduction

"Nothing is so constant as change." (Heraklit of Ephesus, 535–475 BC).

In a world characterised by megatrends such as globalisation, demographic change or digitalisation on the one hand and by global crises such as climate change, the COVID19-pandemic, war in Ukraine, and resulting further crises and shortages e.g. in energy on the other hand, various respective challenges to science and society arise. Thus, actors across all levels of society, politics, research, and economy have to face the consequences resulting from these trends and crises in order to ensure

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future viability of, e.g. resources, production, and mobility. Consequently, processes and strategies need to constantly be reflected, adapted, and transformed in order to be able to foster this challenge of viability.

Major branches of both economy and research in Germany, which underlie those trends and the challenge of constant adaptation presented, are production and (renewable) resources. In order to tackle such overarching and complex topics, the Excellence Strategy of the Federal Government and the Federal States was launched in Germany. With this strategy, Clusters of Excellence (CoE) have been created in order to conduct scientifically excellent research on central topics of today's time, sustainably strengthen Germany as science location, and further improve its international competitiveness (https://www.dfg.de/foerderung/programme/exzellenzstrategie/). Due to the CoE's long-term funding, the adaptation of contents and structures is inherent in their nature, resulting in various chances and often needs for transformation as well. Since the CoE are of interdisciplinary nature, the aim is to foster the complex research questions. This nature also results in further implications with respect to the chances the CoE provide, not only on the technological and scientific levels, but also on the structural and social levels. Therefore, CoE might also be levers of transformation with respect to scientific output and solutions to the trends and challenges, but also regarding structural developments in the German research landscape and how research is conducted in the future. In this article, two CoE are put under investigation in order to describe the (ongoing) transformation in these organisational research units: the Internet of Production (IoP) and the Fuel Science Centre (FSC), which both are currently in their second funding phase. These two clusters will be described in more detail in the following paragraphs for laying the basis of identifying aspects of transformation and providing insights into the hypothesis of CoE being levers of transformation.

The **IoP**, on the one hand, has its origins in the CoE "Integrative Production Technology for High-Wage Countries", which was funded from 2006 to 2017 during the first funding phase of the Strategy of Excellence. It worked on the development of innovative solutions to ensure the future viability and competitiveness of the local manufacturing sector. Success includes, for example, developments of new intelligent production systems, solutions for the efficient production of customised components, end-to-end product life cycle management (PLM) and increasing networking and collaboration. Production technology makes an important contribution to prosperity and social stability in high-wage countries. Manufacturing is one of the core sectors of the European labour market. Confronted with increasingly intense global cost pressures, however, it finds itself caught between the conflicting demands of economies of scale, planning accuracy and forecasting ability, and is exposed to a rapid and value-oriented need for adaptation. The focal points of the cluster's internal research projects were in the areas of individualisation, virtualisation, as well as integration and self-optimisation of production. In the research area of individualised production, the tension between manufacturing customised products as cheaply and efficiently as possible was researched. The goal was to produce economically competitive products from batch size one. The focus was therefore on radically shortening the product development process in order to get from the idea to the individual product as quickly and cheaply as possible. To increase development productivity, the research projects pursued different approaches.

The Internet—in its meaning of a worldwide socio-technical network—has revolutionised accessibility of data and knowledge. This idea has been transferred to the physical world with the concept of the Internet of Things (IoT). A direct application of the IoT approach to production is currently not sufficiently feasible, as there are many more parameters, but much less available data compared with other big data application domains. Modern production is characterised by vast amounts of data. However, this data is neither easily accessible, interpretable, nor connected to gain knowledge. The IoP's vision is to enable a new level of cross-domain collaboration by providing semantically adequate and context-aware data from production, development and usage in real-time on an appropriate level of granularity. The central scientific approach is the introduction of Digital Shadows as purpose-driven, aggregated, multi-perspective and persistent datasets. The IoP will design and implement a conceptual reference infrastructure for the Internet of Production that enables the generation and application of Digital Shadows (https://gepris.dfg.de/gepris/projekt/390621612?language=en).

For the realisation of the IoP, Aachen's highly renown researchers in production engineering, computer science, materials engineering and further necessary disciplines team-up to solve interdisciplinary challenges, like the integration of reduced production engineering models into data-driven machine learning for cross-domain knowledge generation and context-adaptive action. The IoP will be leveraged by the production engineers in order to support a new way of more holistic working on—and with—systems by developing and advancing engineering tools, methods and processes. Therefore, an integrated development for the entire production technology is required. Aachen—as the starting point for the IoP—is characterised by an extraordinary range and outstanding reputation in production research as the results of the previous CoE "Integrative Production Technology for High-Wage Countries" clearly illustrate. The RWTH Aachen Campus offers a unique infrastructural environment including a broad range of research institutes and industrial companies allowing for an integrative development and validation of the IoP. Interdisciplinary collaboration is fostered by an environment that, among others, includes the support of early career researchers by a Research School (https://gepris.dfg.de/gepris/projekt/390621612?language=en).

Big and visionary goals always carry risk both in conception and in the implementation and achievement of research outcomes. Within the IoP, one faces unpredictable challenges—especially in the context of disruptive changes due to new technologies or digitalisation in all areas of society. Future breakthroughs, for example in network technologies (5G networks) or computing power (quantum computing), might enable new alternative approaches to achieving our overall goals, which in turn also promise enormous opportunities. Therefore, the IoP pursues an agile research management approach that allows for continuous adaptation and further development of the planned approach.

For this purpose, the RWTH Aachen Campus offers unique infrastructural conditions with diverse research institutes and industrial partners for the integrative development and validation of the IoP. The balanced composition of participating researchers from five RWTH faculties and six non-university research institutions offers a unique opportunity to realise the vision of the IoP. The setup brings together outstanding researchers from the required disciplines. The participating institutions offer—in addition to principal investigators and associated researchers—more than 11 junior professorships (or equivalent) at the respective institutes. In addition, more than 85 postdoctoral researchers and 500 doctoral students complement the supporting resources. To ensure a significant impact of the Internet of Production, the cluster has access to a unique technical environment. The widespread pool of test benches, real production machines as well as laboratories of the participating institutes offers a first-class infrastructure and the developed and networked digital infrastructure of all participating institutes complements the technical infrastructure to lay the foundation for the IoP (https://www.iop.rwth-aachen.de/cms/Produktionstechnik/Forschung/~rgqp/Struktur-des-Forschungsprogramms/).

The **FSC**, on the other hand, derives from the CoE "Tailor-Made Fuels from Biomass" of the first funding phase of the Strategy of Excellence and continues its work by capitalising on its achievements to act as a structuring element at RWTH Aachen University and its partner institutions. Together with the Forschungszentrum Jülich and the two Max Planck Institutes at the Campus Mülheim, a world-class research environment will be established, which is embedded in a network of strategic partnerships with globally leading research institutions and companies. Joint appointment models for junior research groups, tenure track and lighthouse professorships will create attractive career paths within the German academic landscape.

The increasing availability of non-fossil energy technologies opens unprecedented possibilities to re-design the interface of energy and material value chains towards a sustainable future. The fundamental research in the FSC aims to integrate renewable electricity with the joint utilisation of bio-based carbon feedstock and CO_2 to provide high-density liquid energy carriers ("bio-hybrid fuels"), which enable innovative engine concepts for highly efficient and clean combustion. FSC will generate fundamental knowledge as well as novel scientific methodologies to replace today's fossil fuel-based static scenario by adaptive production and propulsion systems that are based on renewable energy and carbon resources under dynamic system boundaries.

The FSC "Adaptive Conversion Systems for Renewable Energy and Carbon Sources" aims at the generation of fundamental knowledge and novel scientific methods for the development of sustainable technical solutions to valorise renewable electricity and alternative carbon feedstock into liquid energy carriers for CO_2-neutral and near-to-zero pollutant emission propulsion systems. Current research on renewable fuels is focused on fuel replacements for present-day engine technology that are either biofuels from non-food biomass or e-fuels from CO_2 capture and utilisation. FSC goes far beyond this approach by defining the scientific basis for the development of bio-hybrid fuels through integrated design of production and propulsion systems. The targeted technologies are adaptive to anticipate the increasing diversification of energy supply and carbon feedstock availability for a mobility sector in transformation. The (electro-) catalytic production of fuels as well as chemicals is envisaged as an important enabler for flexible and economic value chains. Molecularly controlled combustion systems are targeted to maximise efficiency and minimise emissions during the recovery of the chemically stored renewable energy. Methodological approaches will be developed to assess and ultimately predict the environmental impact, economic viability, and societal relevance of the technical developments. The FSC strengthens disciplinary competences in natural sciences, engineering sciences, and social sciences and converges them in a dynamic team science approach. Forward-integration occurs from fundamental science to the complex systems of fuel production, mobility, and transportation. Simultaneously, system-level information is propagated back by inverse methodologies to enable an integrated molecular and machine design (https://www.fuelcenter.rwth-aachen.de/cms/Fuelcenter/Der-Exzellenzcluster/~smxo/Vision-und-Mission/).

Due to characteristics such as this complexity and long-term funding of the CoE, it can be assumed that they have many starting points and opportunities for transformation. In order to gain more insights into this assumption, the two CoE—IoP and FSC—are described in more detail with specific respect to their contents, structure, and implications on team and work processes within this article. Following this introduction to the clusters IoP and FSC, Chapter "An Actor in the Transformation Triad: The Platform Approach "REVIERa"" presents aspects of transformation within these CoE with regard to the derivation and changes in the contents their research focuses. Analogously, Chapter "Sustainability, the Green Transition, and Greenwashing: An Overview for Research and Practice" describes transformation of these clusters on their structural levels. Chapter "Infrastructures and Transformation: Between Path Dependency and Opening-Up for Experimental Change", then, supplements these levels by deriving the impact of transformation in the CoE with respect to the work and the team processes taking place within the clusters before providing an outlook to possible future onsets of further transformation.

2 Transformation on the Content-Level

Inherent to both CoE under investigation in this article with respect to transformation on the content-level is the adaptation towards new technologies, methods, and processes. This transformation in both IoP and FSC also reflects in the change of the CoE's names from the first to the second funding phase: while the FSC has transformed from "Tailor-Made Fuels from Biomass" to "Fuel Science Centre", the change in the IoP is represented by the names "Integrative Production Technology for High-Wage Countries" to "Internet of Production".

With respect to the latter, content-driven transformation has evolved from the expansion towards a focus on data and the amplified integration of data-oriented and -processing disciplines such as computer and data science on the one hand. On the other hand, the contents of the IoP have also transformed with respect to the processes and research subject since it shows a change from black to green production. With respect to the FSC, transformation on the content-level has mostly derived from the finite nature of fossil fuels and the national strategy for the elimination of combustion engines in the (private) mobility sector.

This content-based transformation of the two CoE derives from environmental and political changes as well as scientific findings that have evolved both outside and inside the CoE since the start of the funding. Due to the major influences such as the climate crisis and finite fossil fuels, for instance, politics and science have reacted by transforming their contents to more sustainable and green solutions to enabling the life as we know it in terms of economy, production, and mobility. Thus, a content-based transformation also shows in both CoE: while the IoP changes its contents from black to green production, the FSC has increasingly oriented itself towards researching forms of fuels from various origins. This pressure to act in both CoE has various reasons: for the IoP, the reasons mainly derive from supply bottlenecks and shortages, energy transition, and a scarcity of resources; for the FSC, the changes predominantly result from political discussions and decisions with respect to the future handling of combustion engines and drive types. As has been shown in a study with 32 experts on the research field of the FSC—i.e. the European alternative fuels market such as politicians, non-profit organisations, and industries like chemistry, aviation, and automotive—the transformation of the fuels market and research is heavily under influence of legal framework conditions as well as the political discussions and goals (Jungnickel et al. 2022). The study also shows that there might be a policy-driven market development resembling an ongoing transition from fossil fuels to alternative ones with the aim of sustainability in those resources (Jungnickel et al. 2022). This transformation,appears to be particularly driven by the European Union Renewable Energy Directive (RED) as well as players such as the mass media and hydrogen-producing companies from Africa, and developments concerning the Northeast Passage as a region for alternative fuels transportation (Jungnickel et al. 2022). Moreover, the FSC's research is also influenced by political decisions and directives, which are made during the respective funding phases. The policy initiative "fit for 55" of the European Green Deal resembles an example for such political decisions with an impact on the FSC as it translates the EU's targets on handling alternative and fossil fuels into legal acts until 2030 (European Commission 2021).

These transformed contents the CoE work on are also reflected when investigating the outputs such as scientific publications. As far as the publications within the CoE are concerned, the topics they cover and are tagged with in, for instance, scientific journals or at conferences and their proceedings have transformed accordingly. Due to the changes in research domains or the orientation of the research focus, the scientific publications refer to these transformed topics as well, since they are a direct output of the CoE's research and reflect the respective processes within them. Across the different funding phases of the FSC, for instance, the main topics, i.e. "chemistry" and "engineering" have remained, but the variety of further topics has transformed (see Fig. 3). Besides the variety of topics (displayed by the differently coloured blocks in Fig. 3, each colour resembling a specific topic), the frequency of mentions within publications (displayed by the number in each coloured block in Fig. 3) has varied as well. During the funding periods, the topic of "energy fuels", for instance, has gained in frequency of mentioning which might derive from the increase of political discussions on the way fuel needs to be realised and (further) developed in order to be or become sustainable. Moreover, material-oriented topics such as “materials science” and “microbiology” in general—in addition to the established topics “biotechnology applied microbiology” and “biochemical molecular biology”—have emerged. This transformation on the content-level of publications as output of the FSC might result from the perceived pressure to act mentioned above as the way fuels are used and produced or developed and is subject to political and environmental debates and transformation themselves.

With respect to the IoP, in comparison, the transformation on the content-level shows in the design and conduct of the regular meetings such as the IoP Conference and Research Summits which both have taken place twice a year since the start of the funding. When considering the agendas for investigating the transformation of this CoE’s contents, it shows that topics have changed here as well. A content analysis of the topics displaying in the agendas provides insights into a transformation towards more ecological and social topics over the course of the funding phases. Social aspects, however, have always been present in the regular meetings such as the Research Summit, the CoE-Conference or different workshops and trainings, which might derive from the existence of a Research School as a means for fostering interdisciplinary collaboration and the (further) development of soft skills. The Research School promotes the development of researchers at different scientific stages (Bachelor and Master Students, Doctoral Students and Postdoctoral Researchers). This includes the promotion of individual careers as well

Fig. 1 Central visual characterisation of the IoP Cluster of Excellence (https://www.iop.rwth-aachen.de/cms/Produktionstechnik/Forschung/~rgqp/Struktur-des-Forschungsprogramms/)

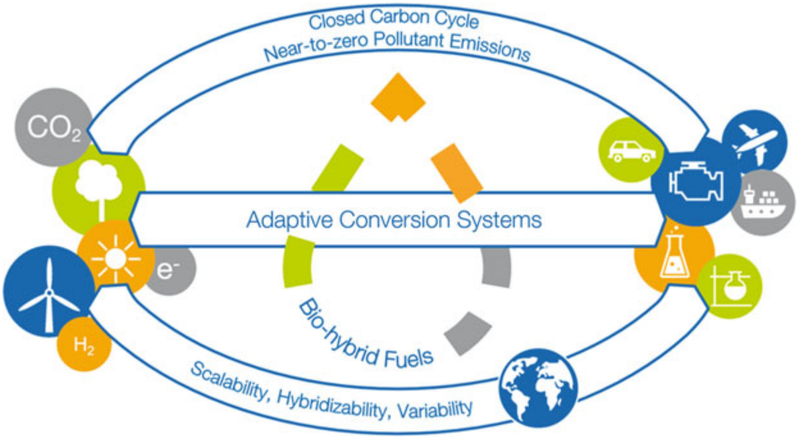

Fig. 2 Central aspects of the FSC cluster of excellence (https://www.fuelcenter.rwth-aachen.de/cms/Fuelcenter/Der-Exzellenzcluster/~smxo/Vision-und-Mission/)

as a systematic training programme that supports new topics and dynamics. Furthermore, researchers have the opportunity to participate in workshops, methodological trainings and micro trainings. The interdisciplinary exchange within the Research School fosters a cross-disciplinary, cluster-relevant learning environment. The main goals are to support academic excellence, promote interdisciplinary collaboration, and strengthen methodological, social, and personal skills. The target groups of the Research School are students, PhD students, and PostDocs.

Regarding the course of meetings, though, the agendas increasingly contain topics from the field of computer science, which complies with the observation that the overall contents of the IoP have transformed across the two funding phases so far. The agendas show a higher frequency of topics such as "digital shadow" and "intelligent production" resembling terms from the interface of engineering and computer sciences (see Table 1). Moreover, the content analysis displays a pursuit for ecological and collaborative topics such as "sustainability" or "cross-linkage to FSC" which might also result from the perceived pressure to act on environmental effects or influences of production.

This transformation on the content-level also brings a need to transform the structural level of the CoE as well which are put under investigation in the following chapter.

3 Structural Transformation

Analogous to the content-based transformation in the CoE, the necessity of transforming the structural level has evolved and increased over the past two funding phases as well. With the broadening of topics that are put under investigation within

Fig. 3 Transformation of topic areas in scientific publications across the funding phases of the FSC (from TMFB 1 to TMFB 2 to FSC)

Table 1 Overview of agenda topics of the IoP (2011–2022)

2014	2015	2016	2017	2018	2019	2020	2021	2022
(Self-) optimisation	Forming technology	Metrology	(Self-) optimisation	Virtual reality	Virtual reality	Internet of production	Networking with FSC	Interdisciplinarity
Automation and robotics	Material sciences	Material sciences	Virtual reality	Data protection	Machine learning	Cybersecurity	Virtual reality	Collaboration
Metrology	Requirements analysis and product development	Interdisciplinarity	Software development and simulation	Machine learning	Usability	Data infrastructure	Machine learning	Interdisciplinary publications
Forming technology	Human factors	Forming technology	Usability	(Self-) optimisation	Interdisciplinarity	Digital shadow’	Machine tools	Vision for next proposal
Optics	(Self-) optimisation	Laser cutting	Metrology	Forming technology	PhD process		Forming technology	Machine learning
Differences to World 4.0	Software development and simulation	Automation and robotics	Material sciences	Metrology	Digital shadow’		Good scientific practice	Internet of production
Machine learning	Machine tools	(Self-) optimisation	Forming technology	Optics			Metrology	Digital shadow’
Meta-research (on research projects)	Optics	Meta-research (on research projects)	Machine tools	Material sciences			(Self-) optimisation	Research data management
Machine tools	Metrology	Optics	Optics	Human factors			eMobility	
Requirements analysis and product development	Automation and robotics	Requirements analysis and product development	Requirements analysis and product development	Creativity and innovation			Requirements analysis and product development	

(continued)

Table 1 (continued)

2014	2015	2016	2017	2018	2019	2020	2021	2022
Laser cutting	Additive manufacturing	Gamification	Machine learning	Business model innovation			Material sciences	
Software development and simulation	Diversity management	Software development and simulation	Production theory	Ethics			Supply chain law'	
Organisational development	Production theoiy	Human robot interaction	Interdisciplinarity				Digital shadow	
Empirical methods	Entrepreneurship	Virtual reality	Additive manufacturing				Digital process chain	
Production theory	Organisational development	Machine tools	Automation and robotics				Intelligent production	

the two CoE and the corresponding increase in complexity of research, there has been a need for fostering and expanding interdisciplinarity, which constantly gains importance. Interdisciplinary collaboration is a challenging task that can lead to new knowledge and solutions. A successful interdisciplinary collaboration of different disciplines does not only refer to the cognitive level but also includes social, communicative, and organisational levels. On the structural level, thus, there is a transformation with respect to the amount of disciplines involved and, correspondingly, the scientific backgrounds of the clusters' employees, particularly the research associates and professors. In the case of the IoP, for instance, the expansion of the contents towards the enhanced inclusion of data science results in the integration of further disciplines such as computer science and data science itself, since it is not sufficient anymore to merely include different fields of engineering sciences which are directly connected to production technology.

This structural transformation is, however, not only dependent on the (further) development of the contents which the CoE's research is focused on. It also results from the overarching, general demand from the labour market and scientific community for educating T-shaped researchers rather than I-shaped ones. Due to the rising complexity of topics and problems to be solved, it is necessary to have people who have a broad as well as deep knowledge on their scientific contexts. Thus, researchers need to be educated deeply in their respective disciplinary field gaining corresponding expertise and deep methodological and factual skills of their discipline, by being simultaneously trained in broad transfer skills for being able to apply their knowledge in another field of expertise and cooperate efficiently and effectively with other disciplines or domains. It, thus, refers to combining hard and soft skills in a single researcher.

The two CoE under investigation in this article represent respective levers to fostering this transformation towards this trend or rather necessity for T-shaped researchers. This characteristic as lever results from their complex contents and structures: on the one hand, they provide the need and offer for (further) developing and applying one's own deep disciplinary expertise with respect to the problems to be solved within the IoP and FSC; on the other hand, they foster the (further) development of broad, transfer expertise as researchers in the CoE need to collaborate with other disciplines, make themselves understood, adapt methods and expertise, as well as integrate theories and results in interdisciplinary teams. For integrating the deep expertise on the disciplinary level, the contents of the FSC and IoP require a respective specified knowledge, methods, and processes in order to conduct the basic research their funding is oriented towards. For facilitating the development of broad expertise, the two CoE provide respective measures and events.

These measures include, for instance, regular meetings to give room for interdisciplinary exchange and foster the communication and discussion across the disciplines involved in the CoE. Thus, such meetings include workshops for strengthening collaboration across both disciplines and use cases or working groups (e.g. CA3 workshops in the FSC) on the one hand, and common meetings for all cluster employees (e.g. Research Summits in the IoP) on the other hand. These measures provide time and space for both disciplinary and interdisciplinary exchange, integrating ideas and perspective in order to form new ways of collaborating and researching within the clusters as well as disseminate insights and results of the research conducted so far. For particularly fostering the interdisciplinary exchange and collaboration, the nature of most of these meetings is moderated and interactive in order to integrate all employees accordingly as well as supporting the chance for transforming the clusters and their research continuously across all hierarchical levels and organisational structures.

The **IoP** includes various working groups, which are divided into Expert Groups and Demonstrators. The four Expert Groups consist of employees from different departments and faculties who are pushing different topics for the Internet of Production. The Expert Group Kubernetes “Cluster4aCluster” is based on an open source software. The Ontology Group addresses ontologies and semantics for the IoP. The Group Artificial Intelligence combines methods of AI research with targeted use cases with the goal of advancing the state of AI research in the IoP. The last group, Future of Work, bundles the competencies of the Future of Work and also focuses on the integration of humans into socio-technical production systems. The demonstrators are divided into electric vehicles, machine tools, and turbomachines.

As a result, an investigation of the potential to transformation on the structural level shows that transformation within such complex and interdisciplinary CoE such as the FSC and IoP requires a specific designation of communication. In order to successfully develop and transform, it is necessary to include and expand existing communicative measures and elements to successfully collaborate in interdisciplinary fundamental research. Moreover, respective communicative skills and measures also provide the chance for successful and effective knowledge management across all employees of the CoE. In order to undergo the structural and content-based transformations presented in Chapters “An Actor in the Transformation Triad: The Platform Approach “REVIERa”” and “Sustainability, the Green Transition, and Greenwashing: An Overview for Research and Practice”, the knowledge across all those included in the CoE needs to be managed in terms of knowing about the included disciplines’ methods, procedures, and theories, but most importantly the results and insights gained so far for further developing the visions of the CoE.

Another aspect of transformation on the structural level with respect to the CoE under investigation is the development of partner institutions. As has been shown in Chapter “An Actor in the Transformation Triad: The Platform Approach “REVIERa””, the scientific publications as output of the research processes within the IoP and FSC show signs of transformation with respect to the contents and topics the authors have written about. When not only considering the topics but also the structural data of publications, such as authors and affiliations involved, this scientific output can also provide insights into aspects of transformation. As for the FSC, for instance, an investigation of the publications across the two funding phases with special respect to affiliations shows an increase in university collaborates who have jointly published with FSC employees (see Fig. 4). In comparison to Fig. 3, the differently coloured blocks in this figure represent the different affiliations the collaborators come from while the numbers within these blocks resemble the number of persons collaborating with the FSC from the respective affiliation. Moreover, the transformation on the structural level represented by Fig. 4 might suggest a strengthening of the collaboration with German (university) partners, as the most frequent affiliations resemble institutions from the German research community such as "DWI Leibniz Institute for Interactive Materials", "Helmholtz Association", "Ruhr-Universität Bochum", or "Research Centre Jülich".

Resulting from the structural and content-based transformations presented above, it is also assumed to have affected the social level of the CoE under investigation. Thus, the impact and implications of those transformational aspects on the contents and structures of the FSC and IoP are discussed in the following chapter.

4 Impact on the Work and Team Processes

As has been shown in the previous chapters, the two clusters FSC and IoP have undergone transformations on various levels for the past decade since they are levers for transformation due to their complex, long-term, and interdisciplinary natures. The particular transformations of contents and structures also results in effects on the employees who actively shape the CoE and conduct the research processes within them. These implications, however, do not only affect the CoE internally with respect to their team and work processes, but also have impact on the IoP and FSC's environment, such as the research community nationally and internationally.

Deriving from the insights on structural and content-based transformations within the IoP and FSC (see Chapters "An Actor in the Transformation Triad: The Platform Approach "REVIERa"" and "Sustainability, the Green Transition, and Greenwashing: An Overview for Research and Practice") it is assumed to be necessary to foster knowledge management across all those involved. Due to changing structures and the continuous developments in methods to use and contents to research on, the researchers who are active in the CoE under investigation need to be supported in terms of sharing their knowledge during the transformational process. Since the IoP and FSC are university-based clusters, they underlie a certain employee turnover, e.g. due to limited time spans of PhD processes which results in continuous potential loss of knowledge and information. However, these pieces of information can be essential during the transformational processes in order to foster their successful conduct. Thus, a cluster-internal implication of transformation is the need for supportive measure considering knowledge management in particular.

As for the CoE under investigation, such measures have been developed and implemented. On the one hand, one supportive measure is the creation of a Research School, which is a group of cluster employees with special focus on providing supportive structures and skills for all those involved in the CoE in order to foster successful interdisciplinary collaboration and exchange as well as the (further) development of soft skills besides the disciplinary research. On the other hand, another supportive measure is the creation of web-based platforms. Both the FSC and IoP have created online platforms for knowledge securing and transfer across their working groups, use

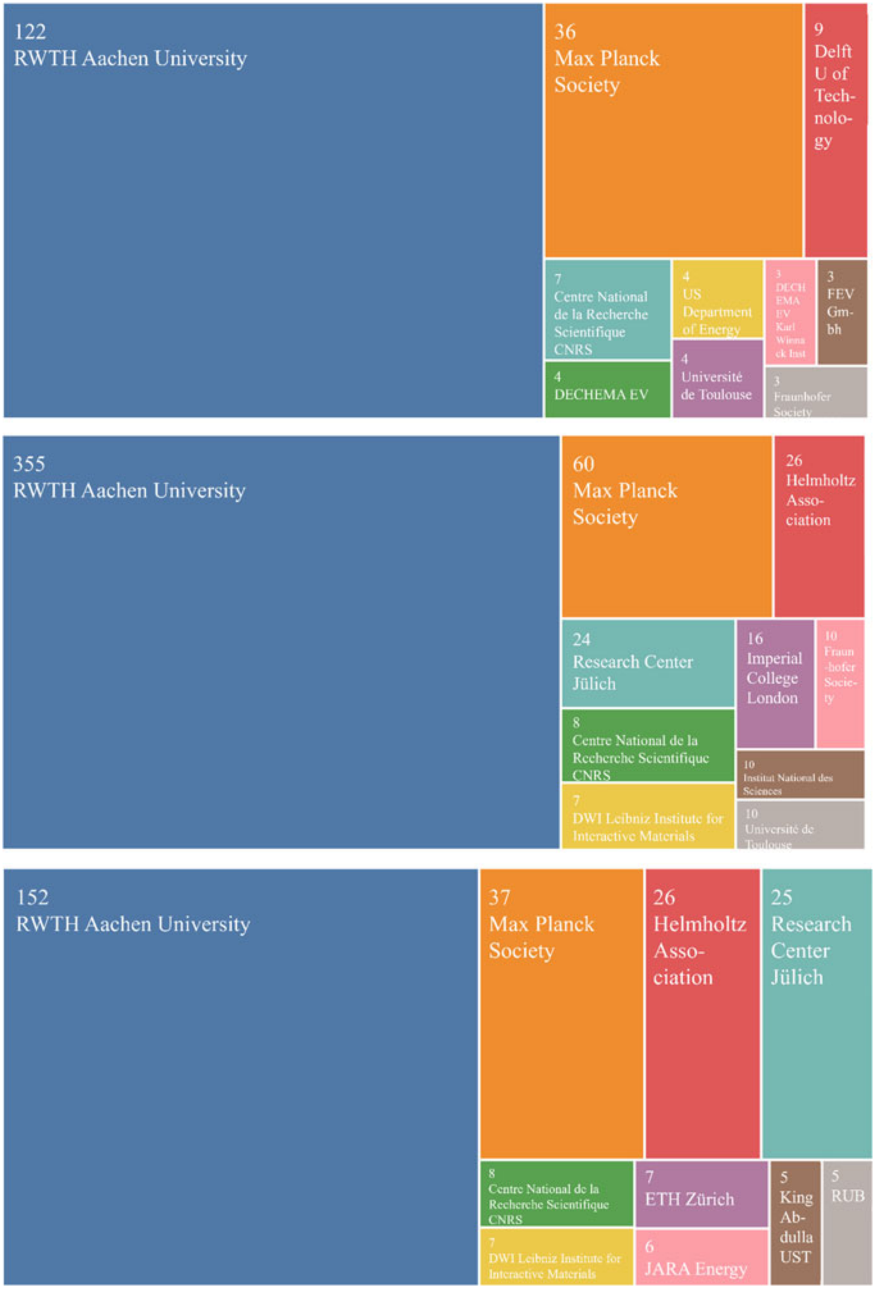

Fig. 4 Transformation of affiliations in scientific publications across the funding phases of the FSC (from TMFB 1 to TMFB 2 to FSC)

cases, events, methodologies, and employees in general. As for the FSC, for instance, the platform currently shows 190 users from 30 different institutes involved in the CoE. It is used for an overview over the CoE in general and its projects included as well as review its findings and processes as it involves more than 40 interdisciplinary projects that are put under investigation within the context of the FSC. Moreover, it supports the knowledge management as it provides crucial information on the processes in the FSC with respect to the nature and contents of the projects, the people who work on them, and the most important results. With these pieces of information, it is assumed to foster transformation by means of facilitating the identification of interfaces between different working groups, employees or institutes involved and the needs for further investigation. Also, the platform provides detailed information on each molecule the FSC researches on by displaying characteristics such as its structure and the need for further improvement or examination. These pieces of information are directly linked to the text description of each project by connecting it to the main results section.

With such measures like the platforms in both CoE under investigation, it is not merely possible to share, manage, and exchange knowledge on the current status of the transformation process, but also to provide insights into possible future interfaces. The implications of the content-based transformation of the CoE also concern the institutes involved in the IoP and FSC and their respective research outside of it. Analogous to the transformation of authorships and affiliations when considering the publications as scientific output of the CoE, the institutes involved have transformed with respect to their cluster-external projects and research as a transformation can be observed that constantly develops away from classic DFG individual proposals towards collaborative projects. Thus, CoE might be considered levers of transformation towards an increase in interdisciplinary collaborative projects due to their interdisciplinary nature that is characterised by close collaboration of employees across different disciplines and institutes.

Correspondingly, the CoE provide both a good visibility inside and outside the scope of the RWTH Aachen University. Due to the high number of people, disciplines, and institutes involved, there is a high chance of expanding the scope of the IoP and FSC's research and impacts. With all these employees and continuously transforming structures, contents, and staff, the CoE represent levers for transformation as they are characterised by a high number of contacts that derive from the partners involved. Thus, these contacts from cluster employees can benefit the CoE in general with respect to meeting the challenges of transformations on the content-level by getting in touch with further experts in the respective fields. Also, the transformations which the IoP and FSC undergo themselves continuously have impact on these contacts and their respective subject areas.

5 Summary and Outlook

As has been shown over the course of this article, CoE represent levers of transformation on different levels. With respect to the contents, they underlie external entities and circumstances fostering or sometimes forcing transformation since the clusters need to adapt their research according to their own findings but also to environmental situations and requirements. As for transformations on the structural level, the IoP and FSC have presented examples of the need to also internally change corresponding to the contents as well. Due to increasingly complex problems and methodologies for solving them, it has become more and more important to network with other institutions outside the CoE as well as foster interdisciplinary collaboration more closely within the CoE themselves.

Thus, the CoE provide chances for transformation due to their interdisciplinary and collaborative nature for fostering future problems and adapting themselves continuously towards future requirements. With their large size and long-term funding, they provide good examples of how transformation is practised and handled in terms of research processes. However, the transformations on the structural and content-based level in particular also raise further questions on the both cluster-internal and -external implications for the employees involved: it might be put under further investigation in the future, thus, if the kinds of jobs have changed that, on the one hand, the clusters look for when searching for new employees and, on the other hand, that the labour market provides.

The IoP has been able to gather various knowledge and research data in the past years. The future goals are to link this collected knowledge and data with each other. In addition, the IoP strives to integrate elementary cross-sectional tasks such as research data management, sustainability in production and structure as well as gender and diversity more strongly into the cluster. Thus, the interdisciplinary of the project becomes clear once again. Another challenge is to continue to promote interdisciplinary cooperation and communication between the various disciplines despite the high fluctuation of employees.

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