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New Ways to Design Next-Generation CAM Systems: An Integrated Approach of Co-Creation and Process Modeling

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ABSTRACT

To face the challenges of digital transformation processes in the course of industry 4.0, the project CAM2030 aims at developing a new generation of CAM (computer-aided manufacturing) systems by integrating novel technologies such as artificial intelligence. The highly innovative development process requires methods that help to include and harmonize the perspectives of different groups (e.g., CAM users and specialists for artificial intelligence) in the development. This paper presents an integrated methodological approach that enhances co-creation methods with process modeling methods. The approach was applied exemplarily and tested in a virtual co-creation workshop. The workshop's goal was to create a shared understanding of the project-specific CAM-planning process and to identify requirements for intelligent CAM systems. The approach proved to be highly productive. A key advantage of integrating process modeling into co-creation is that the perspectives of all actors involved in the innovation process can be captured, considered, and combined having regard to differences in perceptions. In this way, a holistic view on the CAM-planning process can be developed and used as a basis for the system design.

Keywords: Methodological approach for innovation processes, Co-creation, Process modeling, Computer-aided manufacturing, Industry 4.0

INTRODUCTION

CAM (computer-aided manufacturing) systems are common means to increase the flexibility and efficiency of production planning in manufacturing companies. However, their use is highly complex and further impeded by digital transformation processes in the course of industry 4.0. Digital transformation leads to an acceleration of production and innovation cycles. Simultaneously, product individualization and thus the complexity and quality requirements for the CAM-planning process increase (Hehenberger 2020). In consequence, CAM users need extensive (and further expanding) knowledge to solve a growing number of non-standard CAM-planning tasks in increasingly shorter time frames (Jakobs et al. 2017).

To meet these challenges, the joint project CAM2030 aims at developing a new generation of CAM systems based on innovative technologies (artificial intelligence (AI), cloud computing, and evolutionary algorithms). In particular, AI-based automation is used to improve the quality of CAM-parameter optimization. The project consortium is highly interdisciplinary with experts from industry and academia covering various fields such as mechanical engineering, computer science focusing on artificial intelligence and evolutionary algorithms, user interface design, human-centered work design, and technical communication. The development process between these actors is intended to be highly collaborative. In particular, the experts are supposed to develop a shared vision of next-generation CAM systems in several 'face-to-face' workshops. However, aligning the different perspectives on the CAM system and its development criteria proved to be challenging. The issue was further amplified by the restrictions regarding face-to-face meetings in consequence of the Corona pandemic. Therefore, a need to develop methods for collaborative innovation processes under distance conditions (remote work) arose. This paper presents an approach designed for collaboration under remote conditions that enhances co-creation methods (Tandi and Jakobs 2019) by integrating process modeling methods.

The following section 'state of the art' summarizes the foundations used for the proposed approach. The approach is described in the 'methodology' section. The results of the approach's application and insights for its optimization as well as implications for the design of next-generation CAM systems achieved with the approach are summarized in the 'results and discussion' section. The paper closes with an outlook and recommendations for further research.

STATE OF THE ART

Co-creation and process modeling are introduced as far as relevant to the approach.

Co-Creation

Co-creation is a well-established means to support innovation processes (for an overview, see Vorbach et al. 2018). The co-creation approach presented in this paper refers to customer co-creation as "an active, creative and social process, based on collaboration between producers (retailers) and customers (users)" (Piller and Ihl 2009). Co-creation aims at reducing uncertainties in the innovation process, e.g., by integrating customers and their perspectives on products and processes. It provides access to two important types of information: need and solution information. *Need information* relates to customer and market needs, e.g., motives, preferences, and needs of the customers and users of a new product or service. Developing innovative software systems requires a deep understanding of the system, processes, and user-specific requirements. *Solution information* refers to (technological) solution possibilities, e.g., options to implement the users' requirements (Piller et al. 2010).

Co-creation – especially in the case of novel technologies – requires aligning the perspectives of those involved. Actor perspectives include expectations towards the technology under development, perceived goals of the development process, and anticipated development requirements. By establishing a shared 'vision' between actors, the development process is accelerated (Yang et al. 2020). Several methods have been used to achieve perspective alignment, e.g., innovation contests and lead-user workshops. Piller et al. (2010) propose a typology of co-creation methods for actively involving customers in the innovation process based on three dimensions: (i) the point in time when the method is used in the development process, (ii) the number of collaborating partners, and (iii) the degree of freedom the task to solve offers.

The potential of co-creation has been discussed in several studies regarding domains such as e-commerce (Zhang et al. 2022), brand development (Liu 2021), and retail banking (Ferm and Taichon 2021). To our knowledge, co-creation for designing innovative and user-friendly CAM systems has hardly been investigated (Tandi and Jakobs 2019). Overall, there is a need to examine the potentials and challenges of virtual co-creation methods (Benson et al. 2021) and provide guidance for their use in virtual workshops (Shamsuddin et al. 2021).

Process Modeling

Process models are used to visually represent the temporal and logical sequence of activities in a simplified way (Koch 2015). With process modeling, the transparency of processes can be increased (Koch 2015) and process-related communication facilitated to create a shared understanding between process actors (Swenson and von Rosing 2015). Process models can be applied in various contexts, e.g., process optimization or training of new employees (Dumas et al. 2018). In the context of software development, the modeling and analysis of work processes can support requirements specification (Wolf et al. 1999). Process modeling thus offers the potential to increase the communication about and shared process understanding of the CAM-planning process and to support the requirements analysis.

The graphical representation of processes according to a defined notation increases the comprehensibility of process models (Dumas et al. 2018). The graphical notation C3 (derived from cooperation, communication, and coordination) (Killich et al. 1999; Nielen 2014) was developed to model weakly structured and cooperative work processes. Basic elements of the C3 notation are activities and information, which are connected by control and information flows. To model weakly structured processes with not clearly defined predecessor-successor relationships of activities, so-called blobs were introduced in the C3 notation. The C3 notation offers high expressiveness, comprehensibility, and efficiency (see Nielen and Schlick 2016). In view of an increasing number of non-standard process planning tasks (Jakobs et al. 2017), C3 seems to be a suitable notation to model CAM-planning processes.

In studies that focus on co-creation, process models have mainly been used to visualize the co-creation process itself (Durugboa and Pawarb 2014; Eikebrokk et al. 2021). Some engineering studies use process models to improve additive-manufacturing software but do not apply co-creation methods (Belkadi et al. 2018; Oliveira et al. 2017). To our knowledge, process models have not yet been applied to perspective alignment in co-creation workshops for CAM system development.

METHODOLOGY: INTEGRATED APPROACH OF CO-CREATION AND PROCESS MODELING

The approach was developed in three steps: concept development, concept implementation, and concept evaluation. It adapts co-creation methods and integrates process modeling methods based on the C3 modeling notation. The approach follows three assumptions:

1. Early stages of the innovation process benefit from co-creation with users by integrating need information (Piller et al. 2010).
2. Modeling and visualizing CAM-planning processes allows to build up a shared understanding of the status quo as a starting point for the development of new solutions.
3. Co-creation methods can be adapted for remote working conditions.

Concept Development

The concept was developed by experts from the fields of technical communication (n = 3) and human-centered work design (n = 3). The first step was to reconstruct and model the CAM-planning process as it is typical for manufacturing complex products as well as its integration into a higher-level process chain. The CAM-planning process and the higher-level process chain were compiled in two workshops in December 2020 (average duration: two hours). CAM experts (n = 3) demonstrated the process and discussed it with human-centered work design experts (n = 2) and technical communication experts (n = 2). After the workshops, the CAM-planning process and the higher-level process chain were modeled and visualized with the C3 modeling notation. The models were iteratively refined based on feedback from CAM experts (n = 3). The refined models served as a basis for the workshop. The workshop concept was developed iteratively by technical communication experts. The development included the selection of methods, their adaptation for remote working conditions, and their combination. The final concept comprises three workshop stages: preparation, execution, and follow-up analysis; they are described briefly:

Workshop preparation: For each workshop part, aims and tasks of the co-creation process must be defined and described; materials (including a visual representation of the CAM-planning process) produced; and digital tools and formats selected. To facilitate teamwork, the groups (number, composition, size) and roles of the workshop team (e.g., moderator directing the discussion vs. facilitator taking notes or analyzing collected data as input for the next steps) must be defined. Potential participants need to be selected according to the workshop aims and informed, e.g., by an email with the workshop invitation, tasks to be solved before the workshop, and/or documents with additional information.

Workshop execution: The workshop starts with a short introduction and concludes with a summary of the needs for action. The main part comprises the workshop tasks (in that case: warm-up, process model discussion, and requirements analysis).

Follow-up analysis: The follow-up analysis facilitates consolidating and describing the workshop outcomes as input for the further innovation process by reviewing, merging, and visualizing results of the different workshop parts.

Concept Implementation

The final concept was implemented as an online co-creation workshop. The three workshop stages proceeded as follows:

Workshop preparation: The workshop's aim was set to the identification of requirements for the design of AI-enhanced CAM systems. The participant selection covered all stakeholders involved in the innovation process. Participants were invited per email. The email informed about workshop aims, access data for Zoom, and preparatory tasks to familiarize oneself with the workshop topic. In addition, the email provided access to a Google Docs document that included the workshop agenda and detailed task descriptions for breakout sessions and the plenum (task, tool, predefined list, duration). The participants were asked to prepare the workshop in two ways. First, they were asked to check the process models described in an attached document with an explanation of the C3 notation and to answer two questions: (i) Is the status quo of the processes visualized correctly? (ii) What is your role in the higher-level process chain; in which CAM-planning process steps are you involved? The feedback was collected one week prior to the workshop. It was used to evaluate the correctness of the process models and adjust role-related group compositions for breakout sessions. Secondly, the participants were asked to prepare a short presentation (max. three minutes) answering the following questions: (i) Which process steps should be automated? (ii) What are the current weak points of the CAM-planning process? (iii) Which weak points could occur due to automation?

Workshop execution: The co-creation workshop took place in February 2021 via Zoom and Google Docs (duration: three hours including a twenty-minute break). The web-conferencing system was used to record the audio and video stream of the main session and of the breakout sessions. The workshop was led by experts from the fields of technical communication and human-centered work design (n = 2), who were supported by workshop facilitators (n = 5). The participants (n = 14) were experts in the fields of industry- and research-related application of CAM systems (n = 11); software development focusing on artificial intelligence and evolutionary algorithms (n = 2); and user interface design (n = 1). The aim of the workshop was twofold: (i) build up and ascertain a shared understanding of the status quo of CAM-planning processes as described in the models; (ii) facilitate the discussion about requirements for the design of intelligent CAM systems and automation potential based on (i).

(i) Warm-up: The warm-up was designed as a challenge to encourage thinking 'outside the box'. The task was to collect as many no-go design features of CAM systems as possible within seven minutes. For this task, participants were grouped in four breakout sessions. The grouping was carried out homogeneously with regard to the participants' roles (software developers, industry-related CAM users, research-related CAM users, and researchers). In the breakout session, participants documented their results in a shared Google Docs document. In the subsequent plenary discussion, each group presented their top-three no-go design features and contentious issues regarding this ranking within 90 seconds. During the workshop break, the no-go measurements were compared and clustered by the workshop facilitators as input for the discussion of requirements.

(ii) Process model discussion: The discussion started with a short presentation of the process models. Based on the preparatory task, the models were evaluated in two steps. Firstly, the participants' feedback on the process models was discussed regarding the correct representation of the status quo. Secondly, weaknesses and potential for automation in the steps of the CAM-planning process were collected as input for the next part of the workshop. For each evaluation step, the workshop facilitators compiled a list of the key results in Google Docs.

(iii) Requirements analysis: The identification of requirements for partly automated CAM systems involved two steps. Firstly, the participants collected and prioritized functional and non-functional requirements in two separate breakout sessions. To support the identification of diverging perspectives, participants were grouped heterogeneously. The results were documented in a shared Google Docs document. Secondly, the groups presented and discussed their results in the plenum.

Follow-up analysis: The recorded audio data were transcribed and enriched with other information, e.g., notes in Google Docs. The data (enriched transcripts, process models) were used to integrate, categorize, and prioritize requirements for the design of AI-supported CAM-planning processes. The requirements are prerequisites for the developers' design of the new CAM system. They are constantly refined, expanded, and checked for feasibility. The participants' feedback on the process models was consolidated and used to revise the models (for final process models see Burgert et al. 2022). All workshop results were made accessible to the entire project consortium.

Concept Evaluation

The aim of the evaluation was (i) to identify critical aspects of the co-creation workshop concept and implementation and (ii) to improve the approach for further application in collaborative innovation processes under pandemic conditions. The evaluation design focused on two aspects:

1. Is this methodological approach suitable for innovation processes?
2. What are the potentials and challenges of the approach?

The design and output were evaluated by both the participants and the workshop leader team. The participants were asked to give feedback on their overall impression of the workshop productivity and the quality of the results. The workshop leader team reflected upon the selection, combination, and application of the workshop methods and tools for collaboration under pandemic conditions.

RESULTS AND DISCUSSION: OUTCOME AND IMPROVEMENT POTENTIAL OF THE APPROACH

The description of results focuses on (i) content-related insights: need and solution information for the integration of artificial intelligence into CAM systems, potentials for further developing the process models, and further need for action; as well as (ii) method-related insights: potentials and limitations of the methodological approach. The discussion considers the feasibility and improvement potential of the approach.

Content-Related Insights

Participants consistently rated the workshop concept and its results as very productive; the results contribute to the further innovation process in three ways:

No-go design features and requirements for intelligent CAM systems: The warm-up resulted in ranked lists of role-specific and topically clustered no-go features that indicate barriers to the acceptance of intelligent CAM systems. The requirements analysis yielded a structured catalog of requirements ($n = 20$) comprising both inverted no-go features and new aspects. The requirements refer to functions and interfaces of CAM systems; different dimensions of the system's learning ability, in particular learning based on asynchronous feedback; the system's transparency; the user's influence on the degree of automation; the user's expertise; and the design of the user interface. Participants' multiple responses and justifications for certain design issues indicated their importance; the focus is on the customization of automation so that users can easily get in, control, and adjust CAM features according to their knowledge and preferences. The main risks are automated decisions without user control (automation as a black box) and the restriction of the user's flexibility by automation.

Process models: The participants provided important suggestions for the further development of the process models. Based on their feedback, the models were enhanced by renaming and adding – in particular weakly structured – process steps and iterations. The greatest weak points of the CAM-planning process are seen in the CAM parameterization and non-standardized sequences of adjustment activities. They are highly iterative, time-consuming, costly, and therefore offer potential for automation. The risks of automation identified in the no-go challenge were confirmed and completed by the risk that the automated optimization process completely fails.

Further need for action: *(i) Develop a research roadmap:* The workshop revealed the need for a research roadmap guiding the innovation in the future. The workshop outcomes are seen as a starting point for its development. *(ii) Refine requirements for the user interface design:* Automating the CAM-parameter optimization requires new user interfaces for the input of CAM-parameter settings and optimization preferences, the visualization of the optimization solutions, and the user interaction with proposed solutions, e.g., selecting a solution. Identifying requirements for new user interfaces is a relevant step and challenge in the development of intelligent CAM systems.

Method-Related Insights

All participants rated the combination of co-creation methods and process modeling as helpful; potentials and limitations of the methods used are as follows:

Potentials: The approach enables software developers to gain a deeper and broader understanding of role-related needs and requirements and to consider these in the design of intelligent CAM systems. The process models helped to create a common understanding of the CAM-planning process by identifying and merging role-specific perspectives on the topic, e.g., CAM-planning practices in different application fields, such as general mechanical engineering vs. aircraft manufacturing companies. The process models support compensating differences in knowledge regarding the CAM-planning process and provide indications for adaptation needs as a starting point for the requirements analysis. Identifying specific process steps to be enhanced with AI facilitated the derivation of optimization and automation potentials by encouraging participants to describe need and solution information in detail and to relate these to (specific steps of) the CAM-planning process, e.g., when defining requirements. Documenting the participants' findings in a shared document simultaneously engages the participants in negotiating perspectives and clarifying ambiguous information.

The variation of the group composition depending on the task, the decreasing degree of freedom in task processing (starting with a creative and open task), and the presentation of preliminary results contribute to the productivity of the workshop. This applies in particular to the warm-up: The combination of homogeneous groups, a creative task, and a time limit supports the participants in focusing on the workshop topic immediately and rapidly producing first outcomes. The experience of being productive within a very short time was highly motivating. The first visual clustering of no-go measurements offers insights into the type and severity of undesired design features of CAM systems depending on the role of the involved stakeholders. Being aware of those facilitates the identification of improvement potential and the derivation of requirements; participants used the collected deficiencies to transform them into action-oriented requirements before they came up with new ideas.

Limitations: Limitations result from *(i) time constraints*, *(ii) the C3 process model application*, and *(iii) methods and tools for consolidating results*. (i) The approach includes a planned live enrichment of the process models to illustrate weaknesses and automation potentials of the CAM-planning process with icons directly related to the affected process steps. Due to time constraints, this task could not be realized as planned. Instead of enriching the models by icons, the results were documented in Google Docs. This limits the creation of a big picture presenting all process-related issues at once and of a holistic view on the CAM-planning process. The time for identifying key requirements was too short and limited the outcome. (ii) During the workshop, the demand for live adjustments to the process models (e.g., renaming and adding process steps) based on the participants' feedback arose but could not be met for data format reasons; this hampered collaborative process modeling. (iii) Merging results of the group discussions through short presentations in the plenary turned out to be ineffective as it partially led to redundancies and individual interpretations.

DISCUSSION

The discussion is focused on two aspects: (i) the feasibility of the approach under remote working conditions and (ii) recommendations to compensate for limitations.

Feasibility of the approach under remote working conditions: The approach is feasible under remote working conditions with some restrictions. The remote conduction saves traveling time and costs (see also Benson et al. 2021) and thus eases participant acquisition; diverse stakeholders of the innovation process from all over Germany accepted the workshop invitation. However, the near-term accessibility of the online meeting tempted the participants to decide shortly before the workshop (not) to attend (parts of) the workshop. This did not affect the workshop outcome but led to organizational overhead, e.g., adjustments of the group compositions during the workshop. The digital formats of the workshop materials save equipment (pinboards, pen and paper, etc.) and facilitate data sharing, e.g., to prepare participants for the workshop or to consolidate results. Zoom and Google Docs belong to the most commonly used platforms for video conferencing and brainstorming in online workshops respectively, but their use potentially raises ethical issues (Shamsuddin et al. 2021). In the workshop, the selected tools mostly supported the methods used but also showed potential to increase the degree of collaboration by appropriate tools.

Recommendations for further implementation: *(i) Workshop length:* The workshop length needs to be appropriate for the realization of methods, e.g., a four-hour workshop with two fifteen-minute breaks leaves sufficient time for all tasks and allows flexible scheduling. Participants should respond bindingly before the workshop which workshop parts they will attend. *(ii) Software environment for process modeling with C3:* A software solution that allows to easily build and collaboratively modify C3 process models potentially facilitates live adoption of models and strengthens the intertwining of co-creation and process modeling methods. A further development of C3 process modeling solutions could support the embedding of process modeling in later stages of the innovation process. *(iii) Selection of methods and digital tools:* Tools need to be tailored to the tasks and methods. Their selection should be oriented to the functions needed; the desired degree of collaboration and interactivity, e.g., the number of persons using the tool synchronously vs. asynchronously; and the combination of tools regarding the tools' number, complexity, and familiarity among participants. Selected tools should be compliant with the data privacy policy. Online whiteboarding tools, such as Mural, facilitate clustering and prioritizing ideas, e.g., by means of dot voting (participants vote on the importance of ideas by assigning colored dots to ideas they appreciate most/least/etc.). They can help to reduce extensive or complex issues and their interrelationships to the essentials and summarize all results in one picture in a collaborative and interactive way. The consolidation of results can be further enhanced and objectified by asking an independent person to report on the results.

CONCLUSION AND OUTLOOK

There is a lack of research on methods that are feasible for both highly collaborative innovation processes of complex software systems and the application under distance conditions. The Corona pandemic facilitates the development and adaptation of methods for remote working conditions, but further research on virtual co-creation approaches, especially for the design of innovative software systems in the field of computer-aided manufacturing, is needed. Transferring co-creation to the development of next-generation CAM systems and enriching it by process modeling methods is a promising approach. The approach has the potential to involve all actors, especially the user perspective, in the innovation process and generate input for the further development of next-generation CAM systems. It facilitates visualizing the current state of the innovation as well as creating and adjusting a shared understanding of further steps required in the innovation process. The approach is applicable under pandemic conditions but requires careful alignment of co-creation methods with digital work environments.

Future research should focus on the following issues: How can the approach be adapted for back-end co-creation at a later stage in the innovation process? To what extent does the approach provide insights into the impact of AI-based automation on users' working processes and its benefits and restrictions for employees?

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REFERENCES

Belkadi, F., Vidal, L. M., Bernard, A., Pei, E. and Sanfilippo, E. M. (2018). Towards an Unified Additive Manufacturing Product-Process Model for Digital Chain Management Purpose. *Procedia CIRP*, 70, pp. 428–433.

Benson, T., Pedersen, S., Tsalis, G., Futtrup, R., Dean, M. and Aschemann-Witzel, J. (2021). Virtual Co-Creation: A Guide to Conducting Online Co-Creation Workshops. *International Journal of Qualitative Methods*, 20.

Burgert, F. L., Schirmer, M., Harlacher, M. and Mütze-Niewöhner, S. (2022). *Partizipative Erhebung und Modellierung eines CAM-Planungsprozesses für die Fertigung komplexer Bauteile unter Anwendung der K3-Notation*. Aachen: Institut für Arbeitswissenschaft der RWTH Aachen University.

Dumas, M., La Rosa, M., Mendling, J. and Reijers, H. A. (2018). *Fundamentals of Business Process Management*. 2nd ed. Berlin, Heidelberg: Springer.

Durugboa, C. and Pawarb, K. (2014). A unified model of the co-creation process. *Expert Systems with Applications*, 41(9), pp. 4373–4387.

Eikebrokk, T. R., Garmann-Johnson, N. F. and Olsen, D. H. (2021). Co-creation in networks of SMEs: a conceptual model of the co-creation process. *Procedia Computer Science*, 181, pp. 360–366.

Ferm, L.-E. C. and Taichon, P. (2021). Value co-creation and social media: Investigating antecedents and influencing factors in the U.S. retail banking industry. *Journal of Retailing and Consumer Services*, 61, 102548.

Hehenberger, P. (2020). *Computerunterstützte Produktion: Eine kompakte Einführung*. Berlin: Springer.

Jakobs, E.-M., Digmayer, C., Vogelsang, S. and Servos, M. (2017). Not Ready for Industry 4.0: Usability of CAx Systems. In: Ahram, T. and Falcão, C., eds. *Advances in Usability and User Experience. AHFE 2017*. Advances in Intelligent Systems and Computing, 607th ed. Cham: Springer, pp. 51–62.

Killich, S., Luczak, H., Schlick, C., Weissenbach, M., Wiedenmaier, S. and Ziegler, J. (1999). Task modelling for cooperative work. *Behaviour & Information Technology*, 18(5), pp. 325–338.

Koch, S. (2015). *Einführung in das Management von Geschäftsprozessen: Six Sigma, Kaizen und TQM*. 2nd ed. Berlin: Springer Vieweg.

Liu, Y., Li, J. and Sheng, S. (2021). Brand co-creation in tourism industry: The role of guide-tourist interaction. *Journal of Hospitality and Tourism Management*, 49, pp. 244–252.

Nielen, A. (2014). *Systematik für die leistungs- und zuverlässigkeitsorientierte Modellierung von Arbeitsprozessen mit kontrollflussorientierten Notationssystemen*. Aachen: Shaker.

Nielen, A. and Schlick, C. M. (2016). Modellierung wissensintensiver Dienstleistungsprozesse. In: Schlick, C. M., Schenk, M., Spath, D. and Glanz, W., eds. *Produktivitätsmanagement von Dienstleistungen: Modelle, Methoden und Werkzeuge*. Berlin: Springer Vieweg, pp. 171–191.

Oliveira, S. R., Alves, J. L. and Boer, H. (2017). Innovation in the Product Development Process and Performance of firm: An Experience of Value co-creation Based on Incorporation of Technological Innovations by the 3D Modeling and Additive Manufacturing. *Procedia CIRP*, 62, pp. 452–457.

Piller, F. T., Ihl, C. and Vossen, A. (2010). A typology of customer co-creation in the innovation process. *SSRN Electronic Journal*, 4.

Piller, F. T. and Ihl, C. (2009). *Open Innovation with Customers - Foundations, Competences and International Trends*. Aachen: RWTH ZLW-IMA.

Shamsuddin, A., Sheikh, A. and Keers, R. N. (2021). Conduction Research Using Online Workshops During COVID-19: Lessons for and Beyond the Pandemic. *International Journal of Qualitative Methods*, 20.

Swenson, K. D. and von Rosing, M. (2015). Phase 4: What Is Business Process Management? In: von Rosing, M., Scheer, A.-W. and von Scheel, H., eds. *The Complete Business Process Handbook: Body of Knowledge from Process Modeling to BPM*. Waltham: Morgan Kaufmann, pp. 79–88.

Tandi, M. and Jakobs, E.-M. (2019). Two Heads are Better than One: Co-Creation as a Resource for User Interface Design of CAx Systems. In: *2019 IEEE International Professional Communication Conference (ProComm) 23-26 July, Aachen, Germany*, pp. 71–78.

Vorbach, S., Müller, C. and Nadvornik, L. (2018). Der 'Co-Creation Square' - Ein konzeptioneller Rahmen zur Umsetzung von Co-Creation in der Praxis. In: Redlich, T., Moritz, M. and Wulfsberg, J. P., eds. *Interdisziplinäre Perspektiven zur Zukunft der Wertschöpfung*. Wiesbaden: Springer Gabler, pp. 299–314.

Wolf, M., Foltz, C., Schlick, C. and Luczak, H. (1999). Groupware Support for chemical process design. In: Bullinger, H.-J. and Ziegler, J., eds. *HCI International 1999 – Proceedings of the 8th International Conference on Human-Computer Interaction, August 22-26, Munich, Germany*. Hillsdale, New Jersey: Lawrence Erlbaum, pp. 343–347.

Yang, K., Hiteva, R. P. and Schot, J. (2020). Expectation dynamics and niche acceleration in China's wind and solar power development. *Environmental Innovation and Societal Transitions*, 36, pp. 177–196.

Zhang, L., Yang, W., Yang, L. and Gao, L. (2022). How does the value co-creation of e-commerce platform and manufacturers affect channel performance? The moderating role of innovation capability and market turbulence. *Electronic Commerce Research and Applications*, 101120.