11th International Conference on Through-life Engineering Services – TESConf2022
8-9 November 2022, Cranfield UK

Experimental spaces for the introduction of disruptive technologies in production

Björn Papenberg[a]*, Sebastian Hogreve[a], Kirsten Tracht[a]

[a]*University of Bremen, Bremen Institute for Mechanical Engineering (bime), Badgasteiner Str. 1, 28359 Bremen, Germany*
* Corresponding author. Tel.: +49-421-218-64834 ; *E-mail address:* papenberg@bime.de

Abstract

The introduction of disruptive technologies such as artificial intelligence (AI) in the manufacturing industry poses challenges in terms of the subsequent use by employees. When introducing such technologies in the production environment, the introduction strategy must be considered from the outset as part of the product development and the product life cycle. Therefore, the need for a methodical procedure for the transparent and effective introduction of such technologies in the manufacturing industry arises in the context for through-life engineering services. The KI_Café method proposes a way to educate employees through a transparent introduction. A key component of the KI_Café method is a recurring company-public experimental space on the shop floor. In a use case an AI-based assistance system for assessing the cutting-edge quality of milling tools is being developed and then tested in cooperation with two companies. For this purpose, the development of the AI-system is conducted in an interdisciplinary team with employees of the companies. The development process is complemented by conducting workshops with the employees, where they provide feedback to the developers. At defined times during the development phase, the current development status of the AI system is presented at the recurring experimental spaces on the shop floor. This offers the opportunity for all employees to give their feedback on the development process and contribute their own ideas. In addition, various exhibits related to the topic of AI are on display in order to reduce fears in dealing with this technology and to arouse enthusiasm. The findings of the first run of the experimental spaces are that the KI_Café method is a suitable approach for providing employees with competencies regarding AI by focusing on the introduction of an AI-based assistance system.

Keywords: artificial intelligence, through-life engineering, learning factory

1. Introduction of disruptive technologies in the manufacturing industry

The introduction of disruptive technologies and digitalization offers many opportunities for the manufacturing industry. In this context, digitalization is one of the driving factors for change in human work [1]. The use of artificial intelligence (AI) offers the opportunity to solve a plethora of challenges [2]. In this context, AI is seen as a key driver to achieve smart factories [3]. AI can provide strategic advantages by helping employees and decision makers and can be applied in all sectors of the economy [4]. However, the implementation of disruptive technologies is also accompanied by an increased need for employee training. In this context learning in everyday professional life is becoming indispensable due to the shortened lifecycles of technological innovations [1]. Personal competences of employees must be strengthened holistically, so that they are able to take responsibility for networked and cross-divisional processes [1]. Therefore, interdisciplinary cooperation will gain importance in the coming years [1]. Digital assistance systems can be an important starting point for this purpose [1]. These digital assistance systems help employees make complex decisions [4].

The introduction of disruptive technologies in the manufacturing industry poses significant challenges regarding the training of employees. In order for them to accept and use the new technology, the introduction strategy can be seen as an integral part of the product development and the product life cycle.

Learning factories are a suitable approach to increase the acceptance of disruptive technologies in this regard [5]. Daniyan introduces a learning factory concept consisting of five AI-based modules, for the prediction of the temperature variation and the remaining useful life of the wheel-bearings of a rail car [6]. Machine vision application for the application of assembly line quality control and a sorting station are introduced by Zancul in the context of learning factories [7].

The KI_Café method represents an introduction strategy for disruptive technologies that bears

Peer-review under responsibility of the Programme Chair of the 11th International Conference on Through-life Engineering Services.

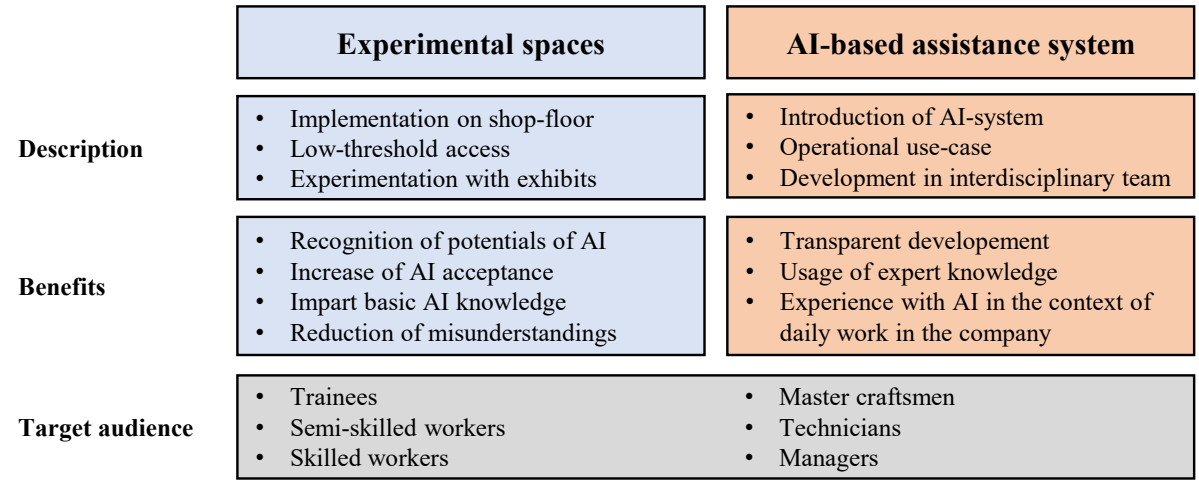

Figure 1: Characteristics and benefits of the method KI_Café

resemblance to learning factories. It consists of two main components that complement each other and thus reduce uncertainties in the introduction process of new disruptive technologies.

Figure 1 shows an overview of the characteristics and benefits of the method. Within the framework of the KI_Café method, companies organize experimental spaces on the shop floor. Employees can experiment with digital exhibits with a focus on AI In these experimental spaces and thus acquire basic AI-specific knowledge.

These experimental spaces are supplemented by an AI-based demonstrator, which is developed jointly with the employees who will use the system. The resulting system is exhibited in its current state of development in the experimental spaces and evaluated by the employees [9].

2. Trust in AI Systems

Studies have shown that most people support the development and use of AI based systems, even though they do not feel like they understand AI and have a low knowledge of where they encounter AI in everyday life [10]. Most people are however interested in learning more about AI [10]. The more employees trust automated, AI-based systems, the more they tend to use them [11]. However, if the employees trust their own abilities more than those of the system, they do not use them [11]. Trust in AI is a central driver for the acceptance and a necessity to realize the benefits of the usage of AI [8,10]. It can be described using different metrics [8,10]. These metrics affect human trust regardless of whether AI is deployed as a robot, virtual assistant or embedded in software [12]. The metrics can be summarized to explainability and interpretability, reliability and safety, performance and robustness as well as privacy and security [13]. They should be mapped through the framework of the development and use of AI applications in order to attain the employees trust [13].

From this context arises the need for a methodical procedure for the development of AI-based systems. Trust is a basic demand for industrial AI applications [8]. As such, a primary goal for a methodical procedure for the development of AI-based systems must be to attain the employee's trust. Trust in AI correlates with an understanding of common AI-based applications and knowledge of AI [10]. Therefore, it is necessary to provide employees with a basic understanding of the functionality of AI based systems and common areas of application.

3. Approach KI_Café

The KI_Café method is an approach for the introduction of disruptive technologies. Within the framework of this approach, experimental spaces are organized in which employees learn basic competencies in the area of AI. These experimental spaces are set up directly on the shop floor to provide a low-threshold access for the employees during their usual working day. While visiting these experimental spaces they can playfully experiment with AI-based exhibits and discuss about AI with AI experts.

In addition, an AI-based assistance system is introduced to support employees in making decisions that were previously made manually. The development process is carried out in an interdisciplinary team and is accompanied by the implementation of the experimental space. [9] The method KI_Café aims to contribute to the research question of how complex, disruptive technologies need to be introduced in the manufacturing industry in order ensure that the employees accept the technology.

3.1. Experimental space

The key component of the KI_Café method is a time-limited experimental space that is intertwined with everyday business life. In order to keep access to the experimental space as low-threshold as possible, it is set up directly on the shop floor. Employees can visit the experimental space during their usual working day without an appointment. To ensure democratic access to the experimental space, all employees of the company are invited, regardless of their professional position.

The exhibits are selected in such a way that they are suitable for low-threshold entry without any prior knowledge on the part of the employees. This makes it possible for employees to acquire basic AI skills in a playful way. These foundational AI skills, as well as knowledge of different application areas of AI-based technologies, help build trust in AI. AI-experts are present at all times to discuss the functioning of the exhibits in particular and AI in general with the employees.

These features distinguish the experimental space of the KI_Café method from other learning factory concepts. The frequency of the experimental space is oriented towards the development process of the AI-based assistance system.

When planning, setting up and supervising the experimental space, care is taken to ensure that employees of the organizing company as well as AI experts are involved. This ensures that the interests of the employees are adequately represented. In addition, the discussion with colleagues offers the employees a low-threshold entry point when visiting the experimental space. The opening hours are chosen in such a way that employees from all shifts can participate in the event. The number of days on which the experimental space is open is determined individually depending on the size of the company.

3.2. AI-based demonstrator

The development of the assistance system is designed in an interdisciplinary way in the context of the KI_Café method. The current state of development is exhibited in the experimental spaces. In addition, workshops are held with the employees. This ensures a transparent development process and allows the expert knowledge of the employees to contribute to the development.

4. Implementation of the experimental space

4.1. Development of an AI-based assistance system for the classification of tool wear

Companies in the manufacturing industry must optimize product quality and production costs to remain competitive [14]. The degradation of cutting tools is one of the most common disruptions in production, which results in the loss of resources and money [15]. The use of worn tools impairs the surface integrity of the products [14, 16]. This reduction of the surface quality may cause the products to be rejected by the customer [14]. Underusage of a tool to reduce this loss of quality results in increased tool costs [14]. In order to minimize the negative effects of the usage of worn tools, accurate predictive maintenance regiments and technologies are required [15]. AI-methods such as convolutional neural networks have proved to be able to accurately predict tool wear [14, 15, 17].

In this context, the implementation of an AI-based assistance system offers the possibility of making the process of evaluating the tool wear more accurate. For the implementation of this case study, the classification of wear on milling tools is chosen as a use case. The entire design data as well as the software code are going to be freely published. The method KI_Café can be used in further implementations for different use cases.

In the development process of the assistance system, establishing trust in the sense of a transparent development process is of particular importance. On the one hand, this trust is established by regularly holding workshops in which the employees can contribute their expert knowledge related to the use case to the development process. On the other hand, the development process is accompanied by the experimental spaces, where the current development status of the assistance system is displayed as an exhibit. Figure 2 shows an overview of the parallel implementation of development work, workshops and experimental spaces at different points in the development process. In one of those workshops, the requirements for the assistance system are collected in an early phase of the development. Based on the identified requirements, the conception and design of the hardware components and the conception and programming of the software are started. The concept of the hardware setup is later validated in a workshop, especially with regard to its applicability in everyday business. Several workshops are held with the employees, in which the procedure for the conception of the AI-based software is discussed. In addition to these workshops, milling tools are classified by an expert in terms of tool wear classification. This classification is used to collect image data, which forms the basis for training the AI-system. The images taken in this way, as well as the imaging device used to take these images, is displayed in the experimental space as an exhibit. This gives employees an early understanding of the functionality of the AI-based system. In addition, employees are made aware at an early stage that the

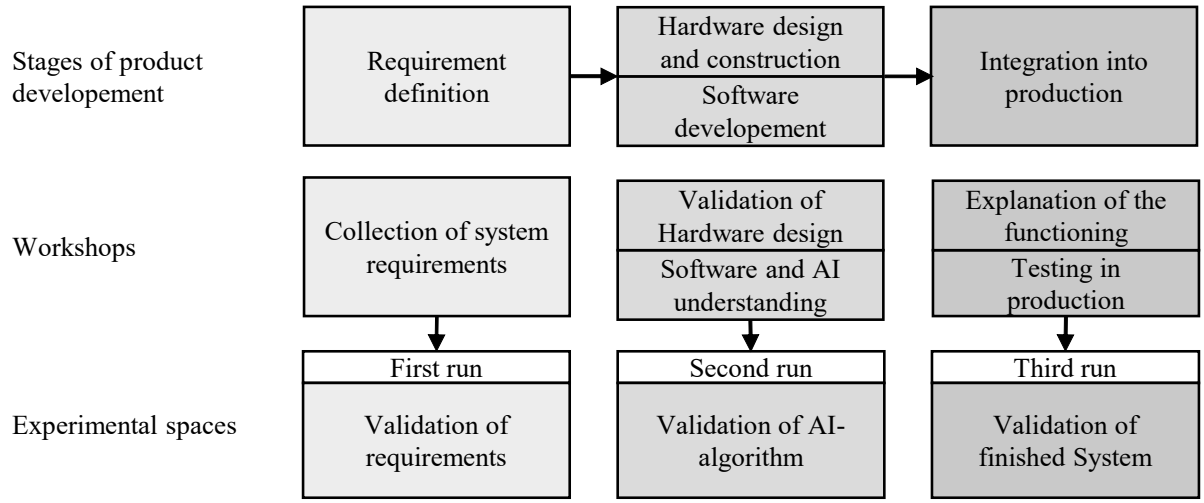

Figure 2: Overview of the stages of product development and their corresponding workshops and experimental spaces

assistance system only processes images of milling tools and not any personal data that requires protection. This increases trust and understanding of how the system works and reduces potential fears with regard to the protection of personal data. The conduction of these workshops is an integral part of the development process. They ensure a transparent development process and increase the employees trust, by enabling them to understand the inner workings of the assistance system. In the future, the second and third run of the experimental spaces and workshops regarding the validation of the finished system will be held.

4.2. Setup and preparation

In reference to the development process, it is decided to carry out three runs of the experimental space over the course of three years. The experimental space within the framework of the KI_Café method is carried out for the first time in two different companies. The duration of the experimental spaces is chosen depending on the size of the company. In one medium-sized company, the experimental space is therefore exhibited for five days. In the case of a small company, the experimental space is exhibited for two days. The duration of the event is agreed upon with the respective companies and based on the expected number of participating employees. As envisaged in the concept of the experimental space, it is ensured

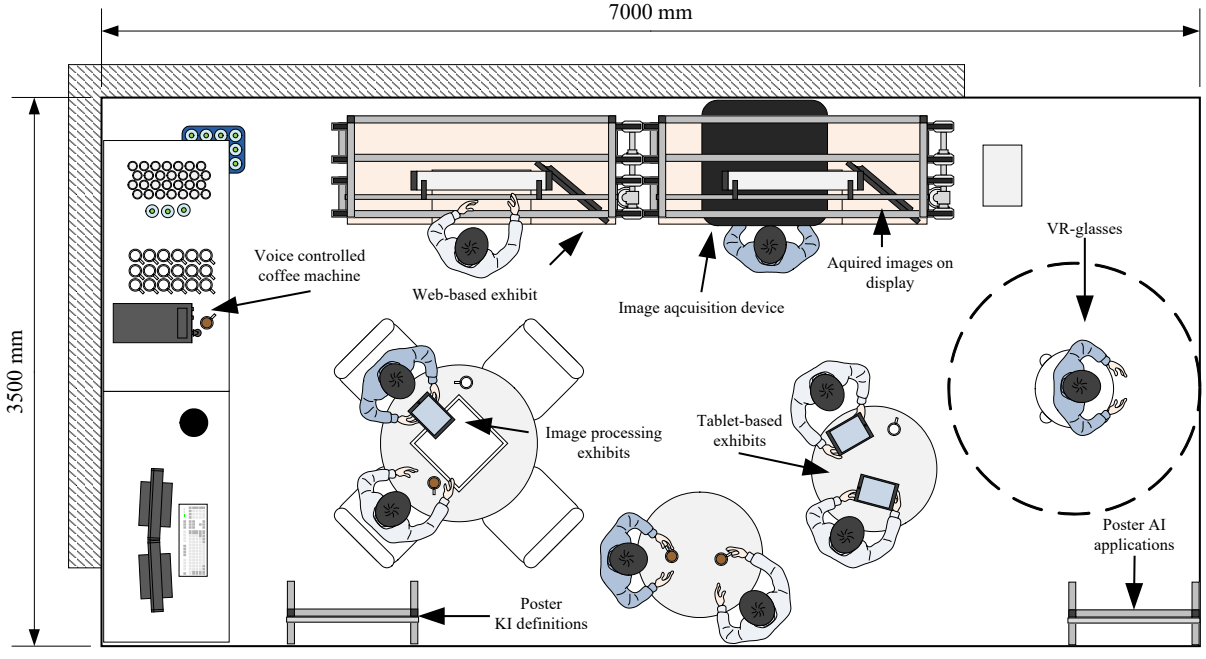

Figure 3: Setup of the experimental space on the shop floor

that employees working in different shifts have equal opportunities to visit the experimental space.

When choosing the exhibits, care is taken to ensure that they are suitable for low-threshold explanations of how different areas of application of AI work. Exhibits from the areas of AI-based speech and image processing are used, since many employees use similar technologies in their private and professional everyday life. In addition to these exhibits, the current state of development of the AI-based assistance system is the centrepiece of the experimental space. It serves to explain the occupation-specific reference of the event to the employees and forms an entry point for discussions with the AI experts. The setup of the experimental space on the shop floor is shown in figure 3. In the run of the experimental space, feedback forms are handed out to identify potential improvements for the further iterations of the experimental space.

4.3. Findings from the first run of the experimental space

The return of feedback forms of the first run of the experimental spaces indicates that the selection and the presentation of the exhibits is perceived as suitable by the employees. The selection of low-threshold exhibits, has proven to be suitable for inspiring enthusiasm. The exhibits related to the everyday life of the employees are particularly well suited to convey to them, where they already encounter AI. In addition, the exhibits relating to their professional environment are particularly relevant for the employees. Here, the interdisciplinary assistance system and the associated exhibit play a special role. Figure 4 shows an AI-expert explaining the design and functionality of the image acquisition device, which is used to manually create an initial, image-based dataset for the training of the assistance system. The exhibit often serves as an entry point for employees to enter into conversations with the AI experts. These conversations, in which the employees share their expertise related to the use case, form an integral part of the further development of the assistance system. Additionally, this participation in the development process increases the acceptance of the assistance system significantly. In the context of these conversations, employees frequently express ideas for use cases of AI in their own, everyday professional lives. The trigger for these ideas is experimenting with AI-based exhibits in the context of the in-house experimental space. The expert discussions are also suitable for clarifying the understanding of AI among the employees, which is often influenced by the media.

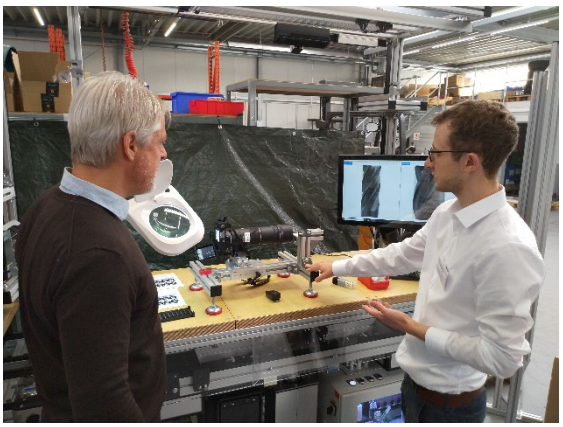

Figure 4: Conversation between an employee and an AI expert concerning the manual image acquisition device

The exhibits shown, in particular the current development status of the AI-based assistance system for classifying wear on milling tools, are able to get the employees excited about AI-based technologies and their potentials. The expert discussions in particular are suitable for reducing fears and misunderstandings about AI-based technologies by creating a basic understanding of how these technologies work. Particularly in the context of assessing the wear on milling tools by the AI-based assistance system, the employees succeed in identifying possible causes of errors in the system and their effects thanks to their job-specific expertise. This information is essential for the further development of the assistance system and is also an entry point for the understanding of error causes and their effects in AI-based systems in general. Understanding these interconnections early in the development process helps to understand and interpret the decisions of the assistance. In a first run, the application of the KI_Café method as an in-house experimental space proves to be a suitable approach for the implementation of disruptive technologies in an industrial environment. The approach proves to be successful in providing employees with competencies in the field of AI in a subtle and playful way. The KI_Café method thus offers an interdisciplinary and interactive approach to the introduction of disruptive technologies in production. In the context of Industry 4.0 and the introduction of AI-based technologies in the manufacturing industry, the KI_Café method enables in-service training for employees, which is coupled with the introduction of an AI system with professional relevance.

The feedback forms suggested that the employees are eager to visit the next iteration of the experimental space and would recommend visiting the experimental space to other colleagues. In the context of the product life cycle, it can be shown that the acceptance of the assistance system can already be increased during the development phase through the use of in-house experimental spaces.

5. Conclusion and Outlook

Within the framework of in-house experimental spaces, employees are offered a low-threshold opportunity to experiment with selected AI-based exhibits and talk to AI experts. In parallel, an AI-based system is developed in an interdisciplinary team. This system is displayed in the experimental space in its current state of development. The run of the first operational experimental space shows that the method is suitable for teaching employees' basic skills in the field of AI. Additionally, the development process of an AI-based assistance becomes more transparent. Furthermore, the development benefits from the application-related expertise of the employees. Thus, the KI_Café method is a suitable approach for the introduction of disruptive technologies in production companies.

With regard to the introduction of an assistance system for the classification of wear on milling tools, two further runs of the operational experimental space are planned in the context of this case study. In the first run of the experimental space, the requirements for the assistance system are validated. The second run of the experimental space includes the validation of the performance of the assistance system with regard to the classification of the wear of milling tools. In the third and last planned run of the experimental space the entire system is validated by the employees. Subsequently, the entire introduction process of the AI-based assistance system is assessed in the context of the KI_Café method and the product life cycle. Afterwards, the construction data as well as the entire software and a guideline for the implementation of the experimental space are published so that other companies can test the KI_Café method independently.

Acknowledgements

The project "KI_Café" ("Einführung entscheidungsunterstützender KI-Systeme in der Produktion") (FKZ EXP.01.00003.20) is funded by the German Federal Ministry of Labour and Social Affairs within the "Zukunftsfähige Unternehmungen und Verwaltungen im digitalen Wandel" program. within the framework of the "Initiative neue Qualität der Arbeit" (www.inqa.de)

References

[1] Jürgens, K., Hoffmann, R., Schildmann, C. Arbeit transformieren!, Forschung aus der Hans-Böckler-Stiftung, Bielefeld, 2017. (in German)

[2] Fritsche, A., Gölzer, A., Industrial Applications of Artificial Intelligence: From Grand Stories of Digital Disruption to Actual Progress, Procedia CIRP 104, 2021, pp. 683-688, https://doi.org/10.1016/j.procir.2021.11.115

[3] Monostori, L., Kádár, B., Bauernhansl, T., et al., Cyber-physical systems in manufactoring, CIRP Annals – Manufactoring Technology 65, 2016, pp. 121–141, https://doi.org/10.1016/j.cirp.2016.06.005

[4] Keller, T., Bayer, C., Bausch, P., Metternich, J., Benefit evaluation of digital assistance systems for assembly workstations, Procedia CIRP 81, 2019, pp. 441–446, https://doi.org/10.1016/j.procir.2019.03.076

[5] Sorko, S.R., Trattner, C., Komar, J., Implementing AR/MR – Learning factories as protected learning space to rise the acceptance for Mixed and Augmented Reality devices in production, Procedia Manufacturing 45, 2020, pp. 367–372, https://doi.org/10.1016/j.promfg.2020.04.037

[6] Daniyan,I., Mpofu, K., Oyesola, M., Ramatsetse, B., Adeodu, A., Artificial intelligence for predictive maintenance in the railcar learning factories, Procedia Manufacturing 45, 2020, pp. 13–18, https://doi.org/10.1016/j.promfg.2020.04.032

[7] Zancul, E., Martins, H.O., Lopes, F.P., da Silva Neto, F.A.T.V., Machine Vision applications in a Learning Factory, Procedia Manufacturing 45, 2020, pp. 516–521, https://doi.org/10.1016/j.promfg.2020.04.069

[8] Mezgára, I., Váncza, J., From ethics to standards – A path via responsible AI to cyber-physical production systems, Annual Reviews in Control 53, 2022, pp. 391–404, https://doi.org/10.1016/j.arcontrol.2022.04.002

[9] Rückert, R., Papenberg, B., Sievers, T.S., Tracht, K. On-site learning factories for implementing artificial intelligence systems in production, Proceedings of the Conference on Learning Factories (CLF), 2021, pp. 281–304, https://doi.org/10.2139/ssrn.3864445

[10] Gillespie, N., Lockey, S., Curtis, C. Trust in Artificial Intelligence: A Five Country Study, The University of Queensland and KPMG, Brisbane, 2021, https://doi.org/10.14264/e34bfa3

[11] Wang, N., Pynadath, D. V., Hill, S. G., Trust calibration within a human-robot team: Comparing automatically generated explanations, 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI), 2016, pp. 109–116, https://doi.org/10.1109/HRI.2016.7451741

[12] Glikson, E., Woolley, A.W., Human trust in artificial intelligence: Review of empirical research, The Academy of Management Annals 14, 2020, pp. 627–660, https://doi.org/10.5465/annals.2018.0057

[13] Emaminejad, N., Akhavian, R., Trustworthy AI and robotics: Inplications for the AEC industry. Automation in Construction 139, 2022, https://doi.org/10.1016/j.autcon.2022.104298

[14] Parwal, V., Rout, B.K., Machine learning based approach for process supervision to predict tool wear during machining, Procedia CIRP 98, 2021, pp. 133-138, https://doi.org/10.1016/j.procir.2021.01.018

[15] Cooper, C., Wang, P., Zhang, J., Gao, R., Roney, T., Ragai, I., Shaffer, D., Convolutional neural network-based tool condition monitoring in vertical milling operations using acoustic signals, Procedia Manurfactoring 49, 2020, pp. 105-111, https://doi.org/10.1016/j.promfg.2020.07.004

[16] Malakizadi, A., Shi, B., Hoier, P., Attia, H., Krajnik, P., Physics-based approach for predicting dissolution-diffusion tool wear in machining, CIRP Annals – Manufactoring Technology 69, 2020, pp. 81-84, https://doi.org/10.1016/j.cirp.2020.04.040

[17] Wang, Y., Zhao, Y., Addepalli, Sri., Remaining Usefull Life Prediction using Deep Learning Approaches: A Review, Procedia Manurfacturing 49, 2020, pp. 81-89, http://doi.org/10.1016/j.promfg.2020.06.015