International Scientific Conference

MOTSP 2025

Management of Technology Step to Sustainable Production

3 - 6 June, 2025, Crikvenica, Croatia

16th International Scientific Conference

Management of Technology Step to Sustainable Production

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Book of

- Abstracts
- Invited lectures
- Posters
- Full papers

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Management of Technology – Step to Sustainable Production

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PREFACE

It is our great honour to present the proceedings of the 16th International Scientific Conference MOTSP 2025, held in the beautiful city of Crikvenica from June 3rd to June 6th, 2025. This annual event continues the tradition of bringing together experts, researchers, and professionals from academia, research institutions, and industry, united by a shared commitment to advancing the fields of technology management and applied production.

The primary aim of MOTSP 2025 is to foster a vibrant platform for exchanging knowledge, innovative ideas, and research results, while strengthening collaboration between science and industry. This year's conference features 43 papers authored by participants from eight countries-Austria, Germany, Hungary, Poland, Slovenia, Slovakia, Serbia, and Croatia-reflecting the truly international and multidisciplinary spirit of the event.

We are especially delighted to welcome our distinguished invited speakers:

- **Filip Šuligoj** (*Advancements in Robotically Assisted Medical Procedures*),
- **Sven Maričić** (*Application of Artificial Intelligence in Additive Technologies: Case Studies in Robotics and Medicine*), and
- **Tomislav Staroveški** (*Innovations in Robotic Sanding and Polishing Systems*).

Their contributions, alongside those of all our presenters, promise to inspire and inform.

The conference program encompasses a broad spectrum of contemporary topics, including advanced manufacturing technologies, digitalization, sustainability, automation, and engineering innovations, all of which are critical to shaping the future of industry and research. Presentations are organized into thematic sessions, providing opportunities for in-depth discussion, networking, and the development of new collaborations.

We extend our heartfelt thanks to all authors, reviewers, and participants for their dedication, enthusiasm, and high-quality contributions, which form the foundation of MOTSP's continued success and reputation.

Associate Professor, Zdenka Keran, Ph.D.

Editor-in-Chief

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Invited Lectures

CV & Abstract

Sven Maričić

Sven Maričić, born 1978, Rijeka. An exceptionally committed and recognized researcher with a recognized history of excellence in education, research, and innovation. Assistan prof. (2015), associated prof. (2019), full professor (2025), presently a professor at the University of Juraj Dobrila in Pula and the Faculty of Medicine at the University of Rijeka. He has significant expertise in creating and presenting compelling lectures and courses, with a focus on the application of additive technologies, robotics, and artificial intelligence in the health sector. He has shown proficiency in establishing collaborative research environments, including research grants and EU H2020 initiatives. The European Commission awarded his 3D and VR Technology for VET project with the European Innovative Teaching Award (EITA). From 2024 member of Biomedix project consortium (Erasmus+ project) in area of additive technologies, biomodeling and 3D printing of medical models. Presently serving as the Head of the Centre for Biomodeling and Innovations in Medicine at the Faculty of Medicine, University of Rijeka, and as the Head of the Laboratory for Robotics and Artificial Intelligence.

AWARDS:

- Awards 2014 City of Rijeka Award for Scientific Contribution
- 2018 State Award of the Republic of Croatia for Science
- 2018 Gold Medal at the 16th International Innovation Exhibition, uSCOPE – the first Croatian 3D printed microscope, ARCA 2018.
- 2019 Special mention of the journal VIDI e-NOVATION award for the best domestic startup in the field of social innovation
- 2021 Silver Medal for Innovation, iENNA, Nuremberg, Germany
- 2022 Gold Medal for Innovation, iENNA, Nuremberg, Germany
- 2023 Bronze Medal for Innovation, ARCA2023, Zagreb, Croatia
- 2023 European Innovative Teaching Award 2023 (EITA), European Commission, Brussels
- 2024 Bronze Medal for Innovation of the Biomodeled Massager, ARCA2024, Zagreb, Croatia

Application of Artificial Intelligence in Additive Technologies: Case Studies in Robotics and Medicine

Sven MARIČIĆ

Artificial intelligence (AI) is being used, among other methods, in the medical field to enhance additive manufacturing, resulting in personalized medicine and advanced surgical solutions. AI algorithms are utilized at various stages of planning, segmentation, and CAx to customize 3D printed prosthetics and implants according to the unique anatomies of individual patients, leading to better outcomes and shorter recovery periods. AI powered design tools and predictive models further advance regenerative medicine and surgical planning. To continue progressing in this field, interdisciplinary collaboration is necessary to address challenges and make the most of AI advancements for next-generation medical technologies. The integration of AI into robotics and medicine is revolutionizing the accurate and effective manufacture of 3D-printed components. AI-driven algorithms in robotics improve the accuracy and effectiveness of 3D-printed parts, allowing for the creation of advanced robotic systems that have enhanced functionality and flexibility. Case examples demonstrate how AI models enhance the optimization of design parameters and accurately forecast material behaviors, resulting in the development of more resilient and adaptable robotic systems.

Keywords: Additive manufacturing, biomodelling, artificial intelligence, CAD

Tomislav Staroveški

Tomislav Staroveški was born on February 21, 1981, in Zagreb, where he completed his primary education and later attended the I. Technical School "Tesla". At the end of his secondary education, he won second place in the 41st Young Technicians Competition of the City of Zagreb and received a distinction for inventiveness at the 4th Inter-County Exhibition of Selected Graduation Projects of Secondary School Students in Electrical Engineering in the field of computer-controlled processes. In 1999, he enrolled at the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb (FSB), majoring in Mechanical Engineering. In 2005, he won a gold medal at the 30th Croatian Innovation Exhibition INOVA 2005. He graduated in May 2007, specializing in Automation and Robotics, with a thesis titled Machine Vision in Industrial Robot Guidance. In November 2007, he enrolled in postgraduate studies in Mechanical Engineering at the Faculty of Mechanical Engineering and Naval Architecture, specializing in Robotics and Automation. That same year, he began working as a junior research assistant at the Chair of Machine Tools, Department of Technology, FSB. In 2009, he was awarded the FESTO Young Researchers and Scientists Support Scholarship. He earned his PhD at FSB in May 2013 with a dissertation titled Wear Modelling of a Medical Drill. At the same Department, he also worked as a senior research assistant from May 2013 to May 2016, and assistant professor from May 2016 to December 2021. Since then, he has been employed as an associate professor. He actively participates in teaching multiple courses at the Faculty, focusing on the mechanical and control system design of machine tools, as well as machining process monitoring. He is a member of the Croatian Association for Production Engineering (HUPS) and the organizing committee of the International Scientific Conference on Production Engineering (CIM), organized by HUPS and the PTW Institute from Darmstadt. Since 2020, he has been a member of the editorial board of the journal Transactions of FAMENA. His research focuses on production and medical engineering. To date, he has authored or co-authored 41 scientific and professional papers, as well as one EU/US patent. He has also participated in over 14 technological and scientific projects funded by the EU and the Government of the Republic of Croatia.

Innovations in Robotic Sanding and Polishing Systems

Tomislav STAROVEŠKI

Advances in robotic sanding and polishing have led to significant improvements in surface finishing quality, consistency, and overall process efficiency. A key challenge in these operations is ensuring precise control over tool engagement while maintaining desired surface characteristics. To address this, recent developments have focused on process monitoring, real-time force control, and adaptive path planning techniques that enhance performance and reliability of sanding or polishing processes. This presentation will cover state-of-the-art methods in robotic sanding and polishing, focusing on force control, and direct and indirect process monitoring approaches aimed for tool condition and surface quality estimation in real-time. Automated path planning strategies, including pre-programmed and adaptive trajectory generation, will be discussed in the context of optimizing tool interaction and ensuring uniform surface quality. Presentation will also address the development of ARCOPS robotic cell, a specialized system for robotic sanding and polishing that integrates both direct and indirect process monitoring subsystems. Key system capabilities, case studies, and real-world applications will be presented. Attendees will gain insights into the latest technological advancements and practical implementations of robotic surface finishing.

Filip Šuligoj

Filip Šuligoj was born on March 25, 1986, in Zagreb, Croa◎a. He enrolled in the Faculty of Mechanical Engineering and Naval Architecture at the University of Zagreb in 2004 and graduated in October 2009, comple◎ng a thesis on the synchronous control of dual-arm robots. A◎er obtaining his master's degree, he con◎nued his academic career by enrolling in a doctoral program focused on Robo◎cs and Automa◎on. In February 2013, he joined the same faculty as an assistant, ini◎ally in the Department of Design and Manufacturing Systems and later in the Department of Autonomous Systems and Computer Intelligence as a senior assistant and assistant professor. He earned his Ph.D. in October 2018 with a disserta◎on that delved into spa◎al registra◎on techniques in robo◎c neurosurgery. Šuligoj has been an ac◎ve contributor to mul◎ple scien◎fic ini◎a◎ves and projects, such as "ACRON – A New Concept of Applied Cogni◎ve Robo◎cs in Clinical Neuroscience," "Applica◎on of Robots in Neurosurgery – RONNA," and the "RONNA – Robo◎c Neuronaviga◎on" structural project. He also par◎cipated in the "CRTA – Regional Center of Excellence in Robo◎c Technologies," a structural project funded by the European Regional Development Fund. As a postdoctoral researcher, he spent a year from March 2020 to March 2021 at the Surgical Robo◎cs Laboratory at the University of Twente in the Netherlands, contribu◎ng to the SAMURAI project (Steering Actuated Probes Under Magne◎c- and Ultrasound-Guidance for Targeted Interven◎ons). In recogni◎on of his contribu◎ons, he received the "FESTO Prize for Young Researchers and Scien◎sts" in 2013 and was part of a team that won the "Best Integra◎on and Innova◎on Award" at the pres◎gious Hamlyn Symposium on Medical Robo◎cs in 2018. Šuligoj is the author or co-author of 20 scien◎fic papers in interna◎onally peer-reviewed journals and 14 conference papers with interna◎onal peer review. Addi◎onally, he serves as a reviewer for an array of scien◎fic journals, including but not limited to Applied Sciences, Expert Systems with Applica◎ons, Transac◎ons of FAMENA, Mathema◎cs, Robo◎cs, Sensors, Fron◎ers in Neuroscience, Fron◎ers in Neurosciences, and IEEE Transac◎ons on Industrial Electronics.

Advancements in Robotically Assisted Medical Procedures

Filip ŠULIGOJ

Robotics in healthcare has brought forth a new era of precision and efficiency in medical procedures. But how exactly are these advancements shaping the future of patient care? In this session, we will explore the cutting-edge techniques used for precise patient localization in robotic medical interventions. The focus will be on image-guided methods, including CT, MRI, and ultrasound (US), which are at the core of these innovations. We will examine both traditional extrinsic methods, such as the use of stereotactic frames and bone-attached markers, as well as more advanced intrinsic, markerless techniques based on anatomical landmarks. Why are these methods important? Because accurate patient registration—combining data from multiple imaging sources—is the key to successful robotic interventions, allowing for integration of advanced technology and medicine. This presentation will also highlight the latest applied research from CRTA (Regional center of excellence for robotic technology) in the fields of neurosurgery, robotic ultrasound diagnostics, and urology. By demonstrating practical innovations, we invite you to look deeper into the future of robotics in medical care, offering new solutions for researchers, academics, and professionals who are navigating the dynamic intersection of computer vision, medical imaging, and robotics.

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Abstracts

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Session A

Achieving resilience in military logistics with cluster-forming technologies

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The combat power of military troops is highly dependent on resilient supply chain management. Recent trends in the application of offensive drone technologies elevate the risks of supply chain failures along the last mile and demand pre-emptive resilience strategies. This paper presents a concept for increased resilience in military logistics that considers requirements elicited with methods from process engineering in collaboration with experts from the Austrian military logistics school. On a basic level, the concept is defined by a) decentralization of repositories at the battalion and company level achieved by cluster-forming technologies, and b) cross-docking for short-time supply points. The precented concept depends on the successful integration of cluster-forming technologies, but if done properly, it has the potential to improve the resilience of modern military logistics.

Keywords: *Clustering, Cross-Docking, Decentralization, Last Mile, Military Logistics, Resilience, Supply Chain Management*

Artificial Intelligence in Knowledge Management: Overview and Selection of Software for Automotive Reporting

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Knowledge Management is essential for modern organizations, enabling systematic capture, organization, and sharing of knowledge to enhance decision-making and innovation. Traditional Knowledge Management tools, focused on document storage and retrieval, struggle with unstructured data and collaboration, necessitating advanced technological solutions, particularly those incorporating Artificial Intelligence. - Artificial Intelligence-driven Knowledge Management systems revolutionize data handling through automation, and real-time insights. This is particularly valuable in data-intensive industries like automotive, finance, and healthcare. In the automotive sector, annual reports provide critical insights but are complex and time-consuming to analyze and are a complex example and therefore a good test case. Annual reports of 5 major automotive companies BMW, Volkswagen group, Toyota Motors, General Motors and Tesla were selected as the testing dataset. Artificial Intelligence tools, using natural language processing and machine learning, streamline data extraction. - Despite their benefits, organizations face challenges in selecting the right Artificial Intelligence-driven Knowledge Management software due to a lack of standardized evaluation frameworks. This research applies to a systematic methodology for assessing such software, considering usability, adaptability, cost-effectiveness, and data privacy compliance, specifically tailored to automotive reporting and gives recommendations for software tools.

Keywords: *Knowledge Management, Software Assessment, Technology Assessment, Artificial Intelligence, Automotive Reporting*

Numerical optimisation of mould and injection moulding process – case study

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The paper presents the optimisation of mould for injection moulding as well as injection moulding process parameters using numerical computer simulation in the Moldex3D software package. The optimisation process will be applied to a specific moulded part and an already manufactured mould. The paper includes evaluation of the existing polymer moulded part and appropriate mould designed and manufactured without application of numerical simulation of injection moulding process. According to the shortcomings found out in evaluation process, by application of numerical simulation of injection moulding process, the optimisation of the mould design well as some of injection moulding parameters was conducted in several stages to achieve as optimal as possible moulded part quality and injection moulding process parameters without dramatic changes in already manufactured mould.

Keywords: *injection moulding, Moldex3D, mould for injection moulding, numerical computer simulation, optimisation*

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Session B

Influence of Innovative Digital Tools in Retail on the Purchasing Behaviour. An Empirical Study Based on a Customer Observation and on a Customer Survey

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Digitalization is fundamentally changing the retail sector, presenting both companies and customers with new challenges and opportunities. Innovative digital tools, such as self-checkout systems, are becoming increasingly important and are not only influencing process efficiency but also the purchasing behaviour of consumers. This study examines the impact of digital innovations on the purchasing behaviour of customers in the retail sector and shows how modern technologies can supplement or even replace traditional structures. The aim of the study is to develop a deeper understanding of which factors promote or prevent the acceptance of digital systems and how these can be successfully integrated into practice. Therefore, this study involves first observations in a supermarket aimed at capturing and interpreting consumer experiences in their natural context. Second a customer survey is conducted in the same supermarket. In summary, while self-checkout systems offer significant benefits, their successful integration requires a balanced approach that addresses the diverse needs of all customer groups. By addressing these needs, retailers can maximize the efficiency and customer satisfaction of digital tools, ensuring their acceptance and long-term success in a rapidly evolving retail landscape.

Keywords: *digital innovations, digital tools, retail sector, self-checkout-systems, purchasing behaviour*

Maintenance and Repair of Battery Electric Vehicles in Germany

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After a surge between 2019 and 2023, Battery Electric Vehicles (BEV) registrations declined in 2024, with customers facing the expiry of state subsidies. In addition, actual studies showed, that the repair costs of BEVs are considerably higher than that of classic Internal Combustion Engine vehicles (ICEV). This research aims to answer the question, why BEVs require higher repair costs than ICEVs, while having a lower technical complexity drivetrain and requiring less maintenance.
Focusing on the research question, a mixed-methods approach is used combining a secondary analysis based on recent studies of insurance companies and road assistances. The study describes the technical differences between BEVs and ICEVs and analyses their maintenance and repair strategy.
Regarding practical and managerial implications, the results could help BEV manufacturers to enhance their product and maintenance strategies. This study could support decision-makers to better understand the BEV market.

Keywords: *Battery Electric Vehicle, BEV, maintenance, repair, cost*

Towards model-based Definition of Digital Product Passports Supporting Sustainable Smart Product Lifecycles

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Sustainability has emerged as a key priority across industries, requiring robust mechanisms to enhance transparency and accountability throughout the lifecycle of smart products. The Digital Product Passport (DPP) presents a solution for achieving these goals by aggregating critical product-related data. However, practical implementation encounters significant obstacles, including fragmented data sources and disparate system integrations. This paper presents an approach that uses the Systems Modelling Language (SysML) to overcome these challenges. First, the DPP's essential components are defined and derived from data generated during product development. Implications from the development of the DPP are summarized and contrasted with the potential of a Model-based Systems Engineering (MBSE) approach. The proposed approach establishes traceable relationships between model elements and DPP attributes, enabling seamless data flow. To validate the feasibility and effectiveness, as an example a 3D printer was developed to create an instantiation.

Keywords: *Digital Product Passport, Product Lifecycle Management, Model-based Systems Engineering, Product Development, Sustainability*

An Ontology-Driven Approach to Improve Data Understanding for Machine Learning Applications in Manufacturing

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The application of Machine Learning (ML) methods represents a significant aspect in the advancement of Industry 4.0. The creation of an appropriate data set for these applications has been identified as the most time-consuming step in the underlying end-to-end pipeline. One of the major obstacles in this process step is to bridge the gap between business understanding and data understanding. To address this challenge, we propose a novel methodology to bridge this gap based on a systematic literature review. Our methodology begins with the construction of an ontology that depicts the underlying manufacturing process along with its parameters. We then show how this ontology can be utilized to deepen the understanding of the manufacturing process. Subsequently, we demonstrate how appropriate target variables for ML-models and suitable data sources can be determined with the support of our ontology. We further elucidate our methodology through a real-world example.

Keywords: *Data Acquisition, Knowledge Graph, Machine Learning, Manufacturing, Ontology*

The Insights into the Implementation and Interdependence of AI and Technological Humanism in Manufacturing Companies

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Manufacturing companies are gaining advantages through the introduction of new technologies, but problems related to human resources, management, and organization have been identified. Industry 5.0 represents a new concept whose goal is to enable the synergy of people and machines. Its part concerning technological humanism is gaining more and more importance due to the very rapid development of new technologies, and it is especially important when considering the application of Artificial Intelligence in companies and the related consequences for the organization and employees. As Artificial Intelligence represents systems capable of performing complex tasks that historically only a human could do, it's influence on human workers is very significant and therefore there is a need for deeper research and understanding. The conducted empirical research provides a technological-humanistic insight related to the implementation of artificial intelligence that companies should consider in order to enable successful collaboration between man and machine.

Keywords: *artificial intelligence; manufacturing companies; technological humanism*

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Session C

Reproducibility of areal topography parameters obtained by atomic force microscope

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[2]Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Ivana Lučića 5, Zagreb, Croatia

In the context of quality management and Industry 5.0, reproducibility is a critical indicator of the ability to achieve consistent and predictable results in laboratories, research, as well as in systems and processes. Reproducibility is also an indispensable component of measurement uncertainty, which quantifies the precision of measurement results. To standardize the measurement procedure for surface topography parameters obtained using atomic force microscope (AFM) and to establish the accuracy and precision of measurement results, an analysis of repeatability and reproducibility was conducted in accordance with the ISO 5725-2:2019 standard, Accuracy (trueness and precision) of measurement methods and results – Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method. Measurements were performed on two AFM standards and a steel sample. The research was conducted over the course of one year and repeated after four years using the same samples.

Keywords: *areal topography parameters, atomic force microscope, reproducibility, quality management, Industry 5.0*

Sustainable Corrosion Protection of Aluminium Alloys – Life Cycle Assessment of established and innovative Coating Processes

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[2]JOANNEUM RESEARCH Forschungsgesellschaft mbH, Institute for Climate, Energy Systems and Society, Climate-neutral Energy Systems and Lifestyles, Science Tower, Waagner-Biro-Straße 100, 8020 Graz, Austria

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Aluminium alloys are highly valued for their lightweight properties. However, their susceptibility to corrosion, particularly in chloride-containing environments, presents significant challenges especially when considering "green" sustainable processing routes. Applying ISO 14040 life cycle assessment (LCA) approach, traditional surface treatment techniques (anodization, conversion coatings, organic paints, plasma activated chemical vapour deposition in vacuum) are compared for the first time to innovative approaches such as Atmospheric Pressure Plasma Deposition (APPD). Although highly conservative assumptions are taken in the life cycle inventory, the greenhouse gas emissions of APPD are clearly lower than in the other technologies, especially because of the higher efficiency in feedstock use, the higher throughput, and the plasma-and air-supported oxidation of CH4, formed during dissociation of the silicon organic precursor. By achieving corrosion properties of cerium-doped APPD silicone coatings similar to the state-of-the-art and elimination of repainting as for organic paints, APPD is at the forefront of sustainable processing.

Keywords: *aluminium alloys, atmospheric pressure plasma deposition, coatings, corrosion protection, life cycle analysis*

Design and implementation of the soft robotic gripper using 3D printing technology

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[2]University of Maribor, Faculty of logistics, Mariborska cesta 7, 3000 Celje, Slovenia

Automated warehouses rely on robotic systems for efficient order picking, yet object manipulation remains challenging due to variations in object shape, size, and material properties. This study focuses on the material selection for the holder of flexible robotic grippers using fused deposition modelling. The holder plays a crucial role in ensuring a secure fit of the gripper's fingers, which is essential for stable and precise object handling in bin picking applications. Testing specimens were fabricated following the ASTM D638-22 standard with a grid infill pattern at full density. Two different variants of Polyethylene Terephthalate Glycol and Acrylonitrile Styrene Acrylate were tested. Mechanical properties, including ultimate tensile strength, elongation at break, and young's modulus, were estimated using a universal testing machine. Results indicate that one variant of Polyethylene Terephthalate Glycol exhibited the highest tensile strength (40.54 MPa), making it suitable for applications requiring high mechanical strength and resistance to tensile loads, while Acrylonitrile Styrene Acrylate provided a balance between strength and flexibility. These results illustrate the comparison of materials and how material selection and infill density impact the mechanical performance of the holder, which contributes to a better choice of material. Future research will explore the influence of 3D printing temperatures, layer height and testing other infill patterns to further enhance the efficiency and reliability of materials used for robotic grippers in robotic manipulation.

Keywords: *Intralogistics, Robotization, Robotic order picking, Robotic gripper, 3D printing, Tensile strength testing*

Superposition methods for topology optimization for non-concurrent loads

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Problems with non-concurrent loads with variable load directions are often encountered in engineering. While dynamic topology optimization more realistically solves such problems, it is also much more computationally expensive and requires complex mathematical formulations and solvers. Hence, in this paper, we compared the performances of three superposition methods for fusing topologies obtained for various load directions. The top88 algorithm was used to generate 91 initial topologies using MATLAB, which were then joined via the superimposition method, weighted-density parameter, and the revolutionary superposition layout method. The performances of superposed topologies were then analysed by calculating their compliances for various load conditions via the finite element method also using MATLAB. The results have shown that the superimposition method and the weighted-density parameter method yield rather similar results. Both methods provided structures with lower total compliances compared to the revolutionary superposition layout method, making them more suitable for problems where stiffness is paramount.

Keywords: *topology optimization, superposition methods, non-concurrent loads, variable load direction*

Calculation driven parametric design of a mechanical assembly on the example of a hook block

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Parametric modeling is a common technology in numerous CAD software packages. One of the advantages of applying parametric modeling is the possibility of forming families of models that share a geometric structure with differences in dimensions. The user is left to generate a new set of dimensions. This paper presents an investigation of the possibility of upgrading the parametric modeling system with the calculation of the mechanical components in the form of a computer program. The user enters a set of operational requirements on the target mechanical assembly based on which the computer program calculates the needed dimensions of mechanical components to fulfill given requirements. The results of these calculations are used to parameterize the model. This approach is demonstrated using the example of a Hook Block model developed within the 3DExperience (3DX).

Keywords: *CAD, Engineering template, Generic model, Parametric modelling, Product families*

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Session D

Ball and Plate Mechanism Actuated with Pneumatic Artificial Muscles

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A novel ball-and-plate mechanism actuated with pneumatic artificial muscles is presented in this paper. The pneumatic muscles are arranged in two antagonistic configuration pairs to generate torque around two axes of plate rotation. The ball-and-plate system is classified as an under-actuated, high-order nonlinear system, with additional nonlinearities introduced by the air compressibility of the pneumatic muscles. A nonlinear mathematical model of the ball-and-plate system has been derived, in which the proposed system is modelled as two ball-and-beam systems, each representing one direction of the ball's movement. Along with the nonlinear equations of motion, a simplified dynamical model of the pneumatic muscles and the proportional valve is included. The linearized model is developed and represented in a state-space form, which is used for LQR controller synthesis. The proposed controller is tested through numerical simulations and experimentally validated on the developed ball-and-plate mechanism setup.

Keywords: *ball and plate, pneumatics muscles, LQR, mathematical modeling*

Economics of polymer electrolyte membrane fuel cells

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Hydrogen is considered a key component of the renewable energy transition for the 21st century, with potential applications using fuel cells in the transportation sector, decentralized heating systems, and energy storage. However, the conversion from fossil fuels to hydrogen implies comprehensive research to address technological and socio-economic challenges, enabling its widespread adoption. This paper discusses the economics of fuel cells. A cost analysis of the polymer electrolyte membrane fuel cells (PEMFC) is performed, and current market data and developments are presented.

Keywords: *Polymer electrolyte membrane fuel cells, cost breakdown, market analysis, economics of fuel cells, PEMFC*

Risk Assessment Procedure for Calibration

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In the product quality assessment process, it is determined whether the product meets the specified requirements. The assessment is based on measuring the specific characteristics of the product. Depending on the measurement uncertainty, the risk of accepting a product that does not meet specifications can be assessed, i.e., the consumer's risk. Conversely, rejecting a product that meets specifications poses a risk for the manufacturer. The standard method of risk assessment by points has been expanded planar and spatially and was applied for risk calculation during the calibration of the roundness measurement device on a moderate scale from −3 μm to 3 μm. A known observation of the dependent variables is used to calculate the producer's and consumer's risk of the corresponding explanatory variable. The risk of calibration was performed for the linearized tolerance interval. Measurement uncertainty of the calibrated value was determined from the regression line by utilizing the propagation of error.

Keywords: *calibration, confusion matrix, consumer's risk, producer's risk, uncertainty*

Design and Analysis of Additively Manufactured Skeletal Structures

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Additive technologies enable the production of elements with complex geometry, which opens up new possibilities in the design of lightweight and strong structures. However, the additive manufacturing process is associated with limitations that must be taken into account at the design stage. This article presents the results of research on the design and analysis of skeletal structures intended for additive manufacturing. CAD models of the robot gripper were developed and then optimized using three different approaches: the use of a shape generator, generative design, and finite element analysis (FEM). The aim of the study was to compare the strength of a robot gripper that was lightened using three different design approaches, with a fixed mass reduction of 40%, in order to determine which method provides the greatest mechanical strength. Experimental studies included numerical analysis and real tests conducted on a testing machine. The test results showed that generative design allows for the most optimal material distribution, which translates into a more favorable strength-to-weight ratio compared to other methods of reducing the weight of the structure.

Keywords: *additive technologies, design optimisation, generative desing, polymeric materials, strength tests*

Additive Manufacturing: A Key to Advancing Injection Molding Efficiency

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The increasing demand for custom-made products, small-batch production, and improved process efficiency is driving manufacturers to adopt advanced strategies that minimize costs and production time. Additive manufacturing (AM) technologies address these challenges by enabling rapid prototyping, design flexibility, and advanced tooling capabilities. Initially constrained to polymeric prototypes, AM now supports a diverse material range, including metals and temperature-resistant polymers. Injection molding is a widely used manufacturing process for producing plastic parts with high precision and repeatability. However, traditional injection molding faces challenges such as high tooling costs, long lead times, and design limitations. This paper investigates solutions to these challenges through the application of additive manufacturing and rapid tooling technologies, emphasizing their potential to transform efficiency in injection molding.

Keywords: *Additive manufacturing, conformal cooling channels, injection molding, rapid prototyping*

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Session E

A MCDA Based Model for Assessing Digital Maturity in Manufacturing SMEs

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This paper presents the findings of research focused on the development of a comprehensive model for assessing the digital maturity of small and medium-sized manufacturing enterprises (SMEs) using multi-criteria decision analysis (MCDA). A systematic review of the literature was conducted to analyse the current state of digital maturity assessment models and evaluate their applicability to the SME sector. The proposed model covers critical digital dimensions relevant to SMEs, including the extent of adoption of digital technologies, the existence of supporting policies and strategies, and the integration of digital technologies into business processes. The developed model enables SMEs to benchmark their current digital maturity level with the desired goals, thus facilitating the formulation of actionable and customized digital transformation strategies. The model was validated through case studies in real production environments to ensure its practical relevance and applicability.

Keywords: *Digital transformation, Strategy, Digital Maturity Model, MCDM, SME*

Systematic literature review about the possibilities for optimizing container loading tasks in the case of intermodal container terminals

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The paper examines the optimization possibilities of container loading tasks regarding intermodal terminals. The research carried out is of great importance, as the role of these terminals is expected to increase in the future based on the forecasts. The research presents the operational characteristics of intermodal terminals well as applicable loading procedures and tools. It analyses current optimization approaches, including logistics and technological developments, using a systematic literature review (SLR). The article explores additional optimization opportunities offered by artificial intelligence, 5G networks and simulation models, which can contribute to more efficient loading tasks and provide higher-quality logistics services. The presented results represent a valuable contribution to the development of railway logistics systems from both a practical and a theoretical point of view.

Keywords: *Container terminals, Intermodal container terminals, container optimalization, systematic literature review*

DISPO 4.0 | Simulation-based optimization of stochastic demand forecast of intermittent material in the capital goods industry

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This paper presents a digital planning approach for intermittent demand utilizing simulation-based optimization to select and parameterize item specific forecasting methods. Demand forecasts are a key lever for efficient inventory and order quantity determination in the planning of spare parts (intermittent demand). Despite their acknowledged potential, digital tools for optimized demand calculation still lack in practice, especially for intermittent material requirements. Thus, the goal of the presented approach is to provide an application-oriented method for optimally selecting and parametrizing forecasting methods designed for intermittent material requirements. Within this methodology, a rule-based selection heuristic is combined with a static simulation of demand time-series and a metaheuristic-based optimization of forecasting parameters, to provide automatically optimized item-specific demand forecasts. Two practical case studies from the capital goods industry evaluate and quantity the application potential. The results indicate a significantly improved, item-specific demand planning of intermittent demand.

Keywords: *Demand planning, intermittent demand, forecasting methods, Croston's method, parameter optimization, spare parts*

Sustainability in drone technology – tracking using drone

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Sustainability and Industry 4.0 technologies are increasingly integrated into modern production. Among these, drones represent a newer autonomous device with potential beyond aerial photography. This paper introduces a novel industrial application of drones: inventory checks and tracking of Autonomous Mobile Robots (AMRs). At the University of Miskolc's Logistics 4.0 Laboratory in Hungary, a roller conveyor system transports unit loads, supported by one larger AGV (Automated Guided Vehicle) and two smaller AMRs. While these ground-based devices navigate independently, their sensing is limited to ground level. The proposed drone solution enhances this system by performing horizontal photographic inventory checks and tracking the movement of mobile robots from above. This dual-purpose use of a single drone improves motion accuracy and reduces the need for multiple tracking systems. The paper outlines the system's design and presents the results of implementing this drone-supported approach.

Keywords: *sustainability, logistics, tracking, inventory check, drone, AMR*

Global logistics in a changing environment and best practices implementation

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The international economic interdependence and transnational organization of goods and services with global supply chains determine the economy, environment and working conditions in many countries around the world in numerous ways. The main risks in the supply chain are of an economic, ecological, political and ethical nature. The EU Supply Chain Act obliges companies to operate fairly and sustainably and to respect human rights and environmental protection along their supply chains. This contribution describes the impact of geopolitical risks on the tactical level of the supply chain. Challenges include costs, disruption and regulatory and compliance issues. A case study of an automotive manufacturer shows supply security and resilient supply chains; risk management in purchasing, e.g. in-house production, Innovations as a strategic competitive advantage; digitalisation; social and environmental responsibility and carbon emissions.

Keywords: *global logistics, environment, disruption, best practices, risk management, supplier*

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Session F

Visualization of social life cycle assessment and ethics audit outcomes in the context of a circular manufacturing ecosystem

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The identification and consideration of social and ethical aspects are key enablers to achieving sustainable production, including human-centrism. Existing social life cycle assessment and ethical audit methods identify relevant risks and their impacts on such complex systems. In the context of a business ecosystem, an integrated view of the assessments' outcomes is missing. Addressing this gap, we propose an extension of the V2 value network notation. By combining economic and social sustainability aspects, the resulting holistic view creates a comprehensive visualization of the overall system. This view serves as the basis for the analysis and communication of complex socio-technical systems' aspects. The proposed extension of the notation is presented, and its application is demonstrated by means of a case study of a platform-based circular manufacturing ecosystem that enables the reuse of assembly lines.

Keywords: *circular economy, ethical audit, social life cycle assessment, sustainable production, value network*

Regulatory Compliance and Innovation. A Literature Analysis on the Impact of Sustainability Legislation on Engineering and Supply Chain Innovations by the Example of the German Circular Economy Act

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This paper examines the effects of sustainability laws on innovation, with a particular focus on the German Circular Economy Act. The study investigates whether strict environmental regulations promote technological advances and sustainable business practices. The results show a differentiated picture. While the German Circular Economy Act and similar regulations encourage companies to adopt resource-efficient practices, the level of innovation varies significantly between industries. Industries such as packaging and high technology are showing remarkable progress, including the development of sustainable materials and optimized product designs for recycling and repair. In contrast, challenges such as high initial costs, technological complexity and regulatory uncertainties make it difficult to innovate, especially for small and medium-sized enterprises. In addition, supply chain innovations are often consistent with lean management principles, which shows how regulatory frameworks can contribute to leaner processes and a reduction in waste.

Keywords: *Regulatory compliance, sustainability, circular economy, innovation, supply chain management, resource efficiency*

Real-time monitoring of the CO_2 footprint of production for SMEs

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The core of the research work is the development and implementation of a real-time product carbon footprint with a focus on applicability for small and medium-sized enterprises. In addition to the life cycle analysis, a central element is the implementation of a machine carbon footprint for a 5-axis universal machining center that records and visualizes resource consumption in real time. With the help of a wide range of sensors, consumption such as energy, compressed air and cooling lubricants are dynamically measured as well as material consumption. The measurement data is then processed, stored and visualized with the help of open-source low-code platforms. This real-time data forms the basis for the precise determination of the production-specific CO_2 footprint. The results of the Product Carbon Footprint show that the greatestsavings potential lies in the choice of sustainable raw materials (a reduction of 38%) and the use of renewable energies (a reduction of 19%). The approach offers a high level of transparency and supports companies in optimizing their processes as well as meeting future regulatory requirements.

Keywords: *CO_2 Footprint, Machine Data Acquisition, Production, Process Data, IoT, OSS*

Bicycle transport – an original solution for building cycle paths on unused railway tracks

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The issue of functional cycle paths is a long-term pressing problem in Slovakia. Cycling combines many benefits that are related to a healthy lifestyle, an environmental approach to transport and, last but not least, the development of the given region. Construction of modular cycle paths on unused railway tracks is one of the possible and modern approaches. The total length of long-term unused railway tracks in Slovakia is approximately 180-220 kilometres. This approach offers several benefits, such as the meaningful use of unused tracks, addressing legal aspects of land use, recycling of unusable waste, or the possibility of quick restoration of the original railroad track. The aim of this article is to present an innovative project for building cycle paths on unused railway lines with the meaningful use of plastic and rubber waste.

Keywords: *Bicycle transport; Original patent solution; Prefabricated panels; Removable system; Modular; Railway tracks*

Grid integration of renewable energies: recent developments of clean energy transition in Germany

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Decarbonization of energy supply has been the main goal of German energy policy for the last decades. With clean energy transformation gaining momentum, with high shares of renewable energies, focus shifts on how to integrate those into the grid system. Decarbonization and grid stability are of utmost importance and are complemented by economic considerations. Cost efficiency addresses layout of transportation and supply grids as well as energy storage and baseload electricity production. This article highlights recent developments of German clean energy transition yielding insights on possible development paths

Keywords: *clean energy transformation, grid integration, renewable energies,*

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Poster Session

The Impact of Inventory Management Innovations on Industry 4.0 Manufacturing Strategies

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In general, the goal of inventory management mechanisms is to develop inventory ordering rules that ensure optimal inventory levels. By "optimal inventory level," we mean a level where stock is always available when needed, while storage costs are minimized. To achieve this, a thorough understanding of inventory-related costs is essential for determining the economical level. In addition to classical and widely used inventory management mechanisms, many companies also employ mixed or hybrid inventory strategies, which are based on the combination of elements from different systems. In Industry 4.0 manufacturing, determining the inventory levels of raw materials and semi-finished products presents a significant challenge for logistics professionals. Developments in Logistics 4.0, as well as advanced hybrid inventory management mechanisms, can provide substantial support to professionals in optimizing inventory levels.

Keywords: *logistics, Industry 4.0, inventory control*

The concept of integrating interactive safety signs into in-plant traffic flow optimization and safety management

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Modern manufacturing companies are characterized by complex internal traffic processes, both pedestrians and forklifts. This results from frequently changing machine locations and thus internal routes, but also from specific production needs, e.g. in the context of customer requirements. Such dynamically developing processes cause problems with ensuring the safety of employees who must move particularly carefully in the production halls. The answer to these problems may be interactive safety signs, which increase employees' attention to dangers, but require a lot of resources for their correct installation. This article presents the concept of implementing interactive signs on the example of a selected production hall. Based on its implementation, a discussion on the required time and cost resources for their installation is also presented in comparison with the benefits and barriers to this implementation.

Keywords: *occupational health and safety, interactive safety signs, safety management*

Integrating Motion Capture Technology into ergonomics design: managerial implications for Systemic Safety Management

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In the era of increasing attention to ergonomic work organization (which also affects employee safety), ways are being sought to improve and detail ergonomic analyses aimed at proposing ways to improve working conditions. One such method may be the use of Mo-Cap technology, which allows for examining the position of employee body segments while performing key activities at work. The results can be at least partially integrated with methods used for ergonomic assessments, e.g. REBA, in order to obtain a more accurate analysis resulting from better recognition of work planes. The presented article focuses on recognizing the possibilities of using Mo-Cap in ergonomic analyses on selected examples. The positive aspects of the application were identified (e.g. better recognition of the employee's body position during work) as well as limitations (e.g. lack of possibility to translate the ad-reading into determining the angles of the body segments' position). The results are presented in the context of supporting the use of ergonomic assessment methods and then analyzed in relation to the benefits of using this technology and barriers to implementing Mo-Cap in ergonomic analyses.

Keywords: *motion capture, ergonomics, system work safety*

A Machine Vision Approach to Assessing Steel Properties through Spark Imaging

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Accurate and efficient evaluation of steel properties is crucial for modern manufacturing. This study presents a novel approach that combines spark imaging and deep learning to predict carbon content in steel. By capturing and analyzing sparks generated during grinding, the method offers a fast and cost-effective alternative to conventional testing. Using convolutional neural networks (CNNs), the proposed models demonstrate high reliability and adaptability across different steel types. Among the tested architectures, MobileNet-v2 achieved the best performance, balancing accuracy and computational efficiency. The findings highlight the potential of machine vision and artificial intelligence in non-destructive steel analysis, providing rapid and precise insights for industrial applications.

Keywords: *Carbon Content Prediction, Convolutional Neural Networks, Deep Learning, Machine Vision, Spark Imaging, Steel Analysis*

Efficient Modification of the CRAFT Algorithm for Layout Optimisation

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Every combination of product mix and production volume requires a suitable layout of workplaces (functional units). An optimised layout is of utmost importance to achieve global competitiveness of companies and to build an efficient, sustainable production. We plan the layout mainly with heuristic methods; constructive, improvement and combined methods are available. In this paper, a modification of the established improvement algorithm CRAFT (exchange method) is presented, which provides much better and more accurate results at a slightly higher computational cost. The most important change is the immediate precise determination of the centroids of the areas of workplaces (or departments) that are exchanged. The distance between any two workplaces is represented by the orthogonal distance between the centroids. In the example given, which is based on a pairwise exchange, the difference is 22 % in favour of the modified algorithm.

Keywords: *production layout, layout optimisation, CRAFT method, pair-wise exchanges, algorithm modification*

Integration Possibilities of Logistics Process Simulation and VR Technology

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Due to the rapidly changing market environment and the increasing complexity of processes, the simulation-based analysis of logistics processes is gaining growing significance. Simulation provides an opportunity to analyse and optimize logistics systems, as well as to conduct preliminary testing before implementation. Virtual reality (VR) can complement this by supporting design, decision-making, and training processes. The primary aim of this publication is not to present simulation modelling or VR technology in general, but rather to examine their potential applications and integration in logistics, with particular attention to synergistic benefits. The most important development directions related to these technologies have been identified. The study focuses on the integration potential of the two fields, which offers new opportunities to enhance efficiency in logistics. The research methodology is inductive, meaning the study was carried out using knowledge gained from practical experience and literature analysis. In addition to exploring and summarizing integration opportunities, the paper also presents the anticipated benefits, providing motivation for applying the solution and for further research in the field.

Keywords: *Logistics, Simulation, Process Development, Virtual Reality*

RFID-Enabled Smart Manufacturing: Real-Time Asset Tracking and Operational Workflow Optimization

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The article presents the possibility of implementing an RFID system to increase transport efficiency in both classic industrial environments and in infrastructure with a high level of automation. The proposed solution takes into account the possibility of installing RFID readers on poles, suspended ceilings, as well as in the floor of the storage and communication space. Thanks to its universal approach and scalability, it allows to increase the level of process automation, especially in SMEs. The implementation of the proposed system in modern factories will make it possible to track in real time the location of products and materials required for production and will have a positive effect on optimizing the flow of these objects within the production environment. Moreover, the implementation of this system is affordable for most enterprises.

Keywords: *RFID; Internet of Things; Industry 4.0; Production management; Internal traffic management*

Optimizing Milkrun Routes: Heuristic Approach for Minimizing Transportation Loops

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Milkrun systems serve as the backbone of material supply for multi-line or parallel manufacturing production, ensuring synchronized and efficient logistics. Despite their importance, route optimization is still largely done manually, leading to inefficiencies. If too few routes are used, transportation time increases, and individual vehicles become overloaded, which is a common issue in current practices. Finding the optimal number of routes is a complex NP-hard problem, requiring advanced computational approaches. While assignment matrices are often available and useful for direct transport allocation, they are not used for optimizing milkrun loops. To address this, a heuristic-based model has been developed that optimizes the number of routes while considering travel length and vehicle capacity. The model and case study integrates genetic algorithms to explore feasible solutions efficiently, balancing the trade-off between too many and too few routes. The proposed approach improves both cost-effectiveness and service reliability in production logistics.

Keywords: *Assigment problem, Heuristic optimisation, Milkrun, Production logistics, Route planning*

Analysis of the possibilities of applying artificial intelligence to modeling and 3D printing of drone elements from polymeric materials

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The subject of the article is to present the possibilities of using artificial intelligence for modeling and 3D printing of drone structural elements from polymer materials. The traditional three-dimensional modeling process based on 3D-CAD systems and the modeling method using artificial intelligence algorithms were analyzed. The project implementation time, design assumptions and accuracy of models obtained using both methods of creating numerical models were compared. Test models produced by 3D printing from polymer materials based on previously prepared numerical data were also presented.

Keywords: *Artificial Intelligence, drone, 3D Printing, 3D modelling, polymer materials*

Strength study of anatomically-similar spongy structures additively manufactured from polymeric materials

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The subject of the article is to investigate the potential to adjust the stiffness of 3D printed plastic implants to match bone stiffness by analyzing design parameters and mechanical properties, considering the spongy structure of the bone. The study consisted of theoretical and practical parts, including original research. In the theoretical part, the definition of implants, the materials used for their production, and the requirements they must meet were discussed, as well as 3D printing methods, with particular emphasis on the FFF method. The static compression test was also described. In the practical part, original research was conducted to verify the possibilities of adjusting the stiffness of the implants. Two 3D models of the L2 lumbar vertebra with different vertebral body thicknesses and internal lattice structures were developed based on literature dimensions. Thirty models with three different lattice densities and two wall thicknesses were printed and subjected to a static compression test. The results showed that an increase in lattice density increased the compression strength of the samples. Samples with thin walls exhibited lower compression strength compared to those with thick walls, regardless of the spongy lattice density. In each group of samples, the results were consistent, indicating good repeatability of the prepared samples. The findings suggest that appropriately selecting the lattice density and wall thickness can significantly improve the mechanical strength of bone implants, meeting the compression strength criteria for the spongy tissue of lumbar vertebrae.

Keywords: *additive manufacturing, compression test, PLA (Polyactide) spongy structure, vertebras*

Aeye: Real-Time Age, Gender and Emotion Detection in Browser

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This paper presents Aeye, a lightweight, browser-based application capable of real-time detection of human age, gender and emotional state using artificial intelligence. Unlike many existing AI systems, Aeye performs all computation on the client side, preserving user privacy and enabling full offline functionality. The application utilizes face-api.js and Tiny Face Detector models, achieving fast and efficient performance even on low-resource devices. Its modular design supports dynamic interface controls and responsive operation across platforms. The scientific contribution lies in the integration of asynchronous model loading, real-time GPU-accelerated inference using TensorFlow.js, and deployment as a progressive web app (PWA). These innovations make Aeye suitable for educational, experimental, and field use cases where connectivity and infrastructure are limited. The paper outlines the system architecture, implementation, and evaluation results, and discusses potential extensions such as multi-face detection and integration with emotion-driven user interfaces.

Keywords: *Face detection, Age estimation, Emotion recognition, Gender classification, Real-time AI*

Industry 4.0 Readiness in Electrical Companies: Analysing Product Manufacturing and Communication in the Customer and Supplier Chain

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This study examines the readiness of electrical companies to adopt Industry 4.0 principles, focusing on the degree of product customization and communication practices within customer and supply chains. Using a questionnaire survey via GoogleForms, data was collected from 28 companies in the electrical industry. The results showed that 63% of companies offer full product customization, indicating advanced technology integration, while 23% of companies only allow partial customization, indicating a transitional phase towards Industry 4.0 adoption. However, 14% stick to fixed product portfolios, reflecting limited flexibility and readiness for digital transformation. The communication analysis further revealed that most companies still rely on traditional methods such as electronic and telephone communication to interact with suppliers and customers, with only 10% achieving fully automated digital integration. This study highlights significant gaps in digitalisation and provides useful insights in terms of technology adoption and communication strategies in line with Industry 4.0 principles.

Keywords: *Communication; Customer; Industry 4.0; Product; Readiness; Supplier Chain*

Advancing Aircraft Maintenance through Predictive Technologies & Artificial Intelligence

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This paper explores the transition in aircraft maintenance from conventional preventative methods to predictive maintenance driven by artificial intelligence (AI). Predictive maintenance utilizes data-driven methodologies to predict failures, reduce downtime and enhance safety. Artificial intelligence plays a pivotal role by processing substantial data to identify patterns and predict maintenance requirements with a high degree of accuracy. The present study addresses the fundamental challenges associated with integrating AI into aircraft maintenance, including robust data collection, algorithm transparency and cybersecurity risks. By addressing these issues, the paper provides actionable insights and solutions to effectively utilize AI while minimizing the associated risks. This study offers a novel perspective on the use of AI to revolutionize aircraft maintenance and improve efficiency and reliability, building on existing research and identifying opportunities to advance AI-driven maintenance strategies in aviation.

Keywords: *artificial intelligence, Industry 4.0, passenger aircraft, predictive maintenance, quality process*

Perceived helpfulness of learning methods for developing logistics competencies in the context of digitalization, sustainability, and Industry 4.0

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This study explores the perceived helpfulness of addressed learning methods in developing competences essential for logistics activities, particularly those related to digitalization, sustainability, and Industry 4.0. A total of 623 respondents, including logistics students, employees, and representatives of logistics associations and leading-edge companies, rated 17 learning methods. The findings reveal a strong preference for experiential formats. Over 95% of respondents rated methods such as real-world problem-solving in companies, the use of professional software, and guided simulations helpful. In contrast, more passive methods like critical reading and independent study were perceived as less effective. Statistically significant differences between students and employees underscore the role of prior industry experience in shaping learning preferences. Survey's results highlight the value of applied learning and closer collaboration with industry in logistics education, offering actionable insights designing training programs that align with the logistics sector's evolving needs.

Keywords: *learning methods, competences, logistics, digitalization, sustainability, Industry 4.0*

Application of AI-based predictive maintenance for industrial processes

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Modern industry is increasingly relying on digital technologies to optimize maintenance processes, reduce costs and ultimately increase productivity. Conventional maintenance models, such as corrective and preventive maintenance, often lead to unnecessary downtime and high operating costs. Predictive Maintenance (PdM), which is based on data analysis and artificial intelligence (AI), enables the timely detection of failures and the optimization of maintenance cycles and is therefore a key component of modern industry. With the advancement of artificial intelligence (AI) and machine learning, data analytics can accurately predict failures, thereby reducing the need for preventive and corrective maintenance in the form that was common before the application of AI. Predictive maintenance (PdM) is emerging as a key element of modern industry, enabling a significant reduction in downtime, an increase in operational efficiency and a reduction in maintenance costs. This paper explores the application of artificial intelligence, including machine learning (ML), deep learning (DL) and the Internet of Things (IoT) in predictive industrial maintenance, analyzes the key implementation challenges in implementation, considers the potential benefits for industrial systems and discusses the challenges and prospects for the further development of this approach.

Keywords: *Predictive maintenance (PdM), artificial intelligence (AI), machine learning (ML), deep learning (DL), Internet of Things (IoT)*