The 16th International Scientific Conference
eLearning and Software for Education
Bucharest, April 23-24, 2020
10.12753/2066-026X-20-151

TOWARDS AUGMENTED REALITY TECHNOLOGY IN CAD/CAM SYSTEMS AND ENGINEERING EDUCATION

Nadezhda SPASOVA and Malinka IVANOVA
Technical University of Sofia, Sofia, Bulgaria, 8 Kliment Ohridski
spasova_n@tu-sofia.bg
m_ivanova@tu-sofia.bg

***Abstract**: Computer-aided design and manufacturing is related to usage of a wide variety of technologies for performance of engineering tasks like: analysis, planning, design, simulation, diagnostics, optimization, producing. The integration of CAD /CAM and AR system play an important role in achieving proper understanding of the 2D and 3D graphical objects modelling. This unity becomes a fundamental part of a standard design process.*

The aim of the paper is to summarize and analyse existing innovative solutions in utilization of augmented reality in computer-aided engineering practice and received knowledge to be used in the courses from Higher education. Also, the exploration about augmented reality usage in teaching, learning and assessment in university courses is performed in order to be chosen technology solution for delivering the knowledge in the context of CAD/CAM systems.

The research method for review performing is based on examination of scientific papers indexed in SCOPUS and Web of Science, indexed by search engines Google Scholar, Google Search and Semantic Scholar. The keywords augmented reality, CAD, CAM, product design, product manufacturing, engineering, are used for forming several searching queries, investigating the topics concerning AR in CAD/CAM systems.

A conceptual meta-model outlining the utilization of augmented reality technology in CAD/CAM systems and application of this knowledge for engineering education is developed. It consists of two parts. The first part describes the AR technology usage in CAD/CAM engineering process that includes several stages in design and manufacturing of products. It can be said that many of the stages are supported by AR for documentation, presentation and experimentation. The second part explains the usage of AR technology in engineering education. An AR-based eLearning system should possess features for teaching, learning and assessment through usage of AR web-based, mobile-based or combined technologies. The summarized knowledge about facilitation of activities in CAD/CAM process through AR will be used for educational purposes and delivered also with AR technology.

***Keywords:** Augmented reality; engineering education; CAD/CAM; engineering process, eLearning*

I. INTRODUCTION

Augmented reality (AR) is technology that allows human-machine-world interaction to be improved and the gained user experience to be enhanced, personalized or created in collaboration. Virtually presented 2D/3D objects are added to the real world scene or situation for further explanation, clarification or evaluation of real objects, events or processes. Overlaid AR objects are computer-generated and visualized through utilization of different machine learning and artificial intelligence techniques and with support of a wide variety of technical devices like head-mounted helmets, cyber gloves, wearable glasses, aural and haptic displays. Also, AR scene could be implemented through usage of markers that contain the needed information for AR objects presentation. Computer vision methods are adopted for tracking and recognition of markers, images, interested points by cameras of smart devices and computers [1]. Contemporary mobile smart phones and tablets contribute to receiving ubiquitous AR experiences by mass users. Spatial AR technology gives possibilities for presentation of virtual information onto the physical objects in the surrounding environment through use of video projectors, holograms, radio frequency tags and users do not have to wear or take any displays. GPS systems, gyroscopes, accelerometers, rotating sensors and electronic compasses contribute to identification of user's geolocation. Van Krevelen and Poelman classify the AR technologies in three groups according to the display technology that creates illusion for overlaying the virtual AR object onto real one: (1) Head-worn display (HWD) technology that includes a display/displays (head-mounted displays, virtual retinal display and head-mounted projective display) connected to the computer; (2) Hand-held display (HHD) and projector technology that the AR objects are seen through mobile devices, personal digital assistants and projectors; (3) Spatial AR (SAR) uses statically situated displays and projectors in exhibition and presentation places and the user interaction is limited [2].

Nowadays, the AR technology is in progressive development and according to Forbes [3] AR changes the way of our life, work, teaching and training. Trending issues of AR technology are related to increase utilization for indoor and outdoor navigation, for shopping, for assistance in automotive industry and other spheres like military, medicine, enterprises [4]. The prediction for the next several years is that the AR will be in the extensive development for the purposes of engineering, education, healthcare, live events, real estate, retail, military, video games, video entertainment.

The increased interest to AR is also proved through the funded by European Commission projects which aim is to facilitate research and innovation in producing AR frameworks, systems and applications: the VOSTARS (Video Optical See-Through Augmented Reality Surgical System) project creates a medical solution for improvement of visibility at surgical operations [5], the INSITER (Intuitive Self-Inspection Techniques using Augmented Reality for construction, refurbishment and maintenance of energy-efficient buildings made of prefabricated components) project uses AR as a connective bridge between virtual models and physical buildings to achieve high quality between design and realization [6], the DIMPA (Digital Innovative Media Publishing for All) project trains learners in operation with the emerged new technologies in content publishing [7].

The existing practice and predictions define AR technology as promising and challenging solution in many industries and it can be seen that the engineering and education are among the trending priorities for its extensive adoption.

The aim of the paper is to summarize and analyze AR approaches in computer-aided engineering and in education focused on studying systems for computer-aided design (CAD), computer-aided manufacturing (CAM) and computer-aided engineering (CAE). The findings reached after performed exploration lead to development of meta-model regarding AR technology utilization in computer-aided engineering and model explaining how AR contributes to teaching, learning and training in the area of CAD/CAM/CAE systems.

II. RESEARCH METHOD

The performed review is based on examination of scientific papers indexed in SCOPUS and Web of Science, indexed by search engines Google Scholar, Google Search and Semantic Scholar. The keywords *augmented reality*, *CAD*, *CAM*, *product design*, *product manufacturing*, *engineering*, are used for forming several searching queries, investigating the topics concerning AR in CAD/CAM systems. The found results are ordered through their relevance to the searched keywords. The first 50 results are taking into consideration for further exploration. The queries, formed and limited in the similar way are constructed for conductance of exploration related to AR technology in educational practice. The used keywords are: *augmented reality*, *engineering education*, *higher education*, *teaching*, *learning*, *assessment.*

III. AUGMENTED REALITY IN CAD/CAM SYSTEMS

The computer assistance in design, analysis and manufacturing of products is a wide implemented practice by enterprises for automation of many tasks that are related to cost and production time reduction, team performance improvement, failure risk decrease and product quality achievement. The technology concerning computer-aided design assists creation, modification, analysis and optimization of product design through usage of computer software [8]. The computer-aided manufacturing uses computer technologies for planning, managing and controlling manufacturing activities. Often CAD and CAM systems operations in one enterprise are coordinated and then computer-integrated manufacturing (CIM) process is realized. The technology involved in computer-aided engineering allows analysis of created CAD model to be conducted through simulation of its features and behavior with aim to be valued, modify or repair [9]. The relationship between CAD and CAM systems provides the product realization from idea to manufacturing. This important connection is represented by the authors' creation (figure 1).

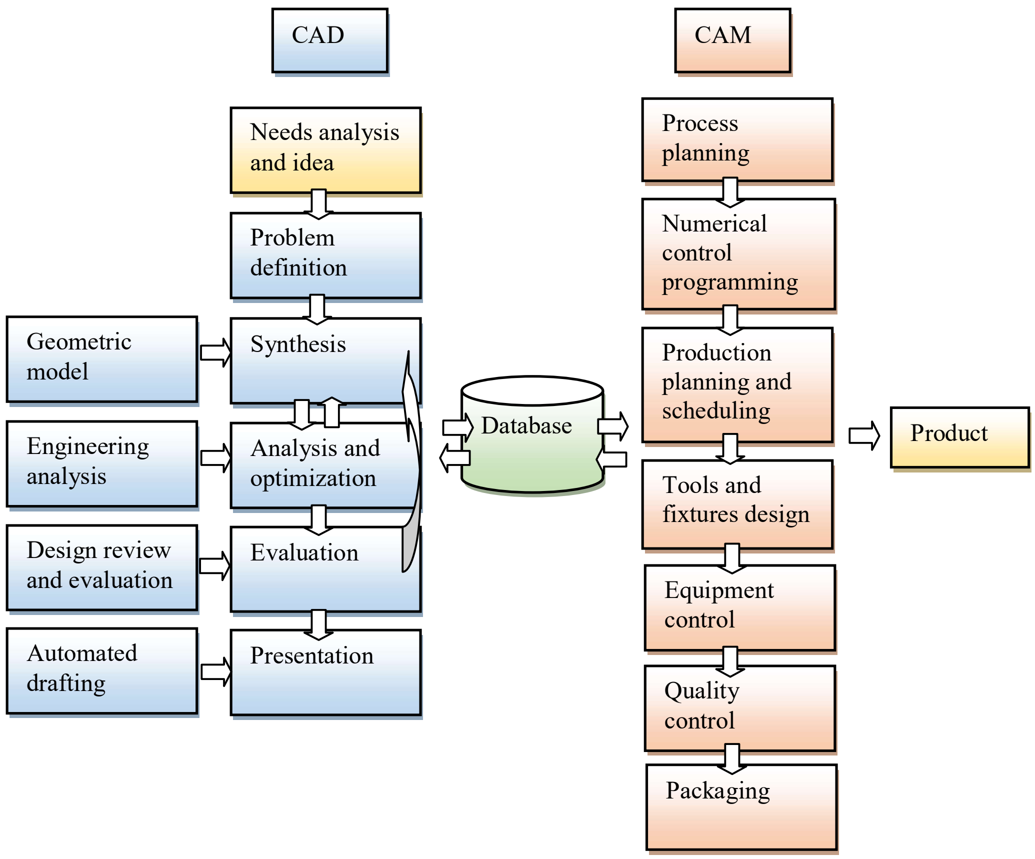

Figure no. 1. Relationship between CAD and CAM systems at product realization

AR technology usage in support of different phases of product design and realization is discussed in several scientific papers showing its advantages and benefits for manufacturers, workers and end-users.

Arbeláez-Estrada and Osorio-Gómez are developed a mobile application for Android smart devices that offers possibility to end-users to give their feedback about the conceptual design of a product [10]. Preliminary user evaluation of aesthetical product view will increase the successfulness of the final manufacturing product.

Uva et al. validate the AR technology usefulness in several critical phases of product development process [11]. In design phase, a printed document with technical drawing includes an AR marker for visualization the 3D view of the product. In the phase of analysis and optimization, AR technology visualizes the 3D view of products when the simulation parameters are changed and also several design configurations are tested and visualized to be chosen the optimal one. Quality inspection of manufactured geometries of a real prototype is done in the phase of product quality control.

Santos et al. propose an application of AR suitable for conceptual design and re-design of product's shape characteristics [12]. Its usage is appropriate for interactive 3D functionality modeling in the early stages of product development. The method allows combination of physical prototype and virtual model and applies tape drawing techniques for interactive visualization of prototypes in real size.

Giunta et al. summarize existing solutions in AR usage in different stages (*task description* – needs analysis and idea, *design specification* – problem definition and principal solution development, *concept* – construction structure development, *preliminary layout* – list with parts and assembly documents preparation, *definitive layout* – production and operating documents preparation, *product documentation*) of design process [13] and their exploration leads to the following conclusions: (1) The AR technology is not used at task stage; (2) The stages of design specification and product documentation are supported with few applications; (3) The concept, preliminary layout and definitive layout stages are very well facilitated taking into account the AR technology advantages; (4) The most used AR technologies are: hand-held, head-worn video and spatial projection; (5) The spatial optical and head-worn retinal AR technologies are not preferred because of the implementation difficulties.

Novak-Marcincin et al. present a developed application for supporting the manufacturing assembly process that is enhanced with usage of augmenting virtual AR parts on a core product [14]. The benefits for engineering stuff are that they receive important visual information regarding the position and orientation of a product and visual representation of the next part according to the manufacturing process plan. That can avoid several problems in items assembly at product manufacturing.

Segovia et al. propose a software solution for production monitoring and quality control giving visual information on the production line [15]. Current and historical data could be presented and a tendency to be revealed concerning the operations on several work stations. That makes decision process easier and time for monitoring is reduced. The created AR system is also used to educate users to terms related to the production quality.

Doil et al. introduce their AR system for facilitation the tasks in manufacturing planning [16]. Virtual planning objects are overlaid on the real production environment and this method lead to the validation of the planning tasks. AR technology is seen as a factor for improvement of the planning stage of the industrial process.

Malik et al. propose a method for receiving dynamic information about the quality of an object, manufacturing during the printing process [17]. The 3D object is scanned layer-by-layer and the outer shape is controlled. This allows the potential defects to be detected directly during the printing process. Also, the user interaction is improved through usage of AR glasses. The decision making is facilitated.

Mengoni et al. present SAR system with two modules – the first one is ergonomic for monitoring the worker posture during the conduction of assembly operations and the second one is assembly support module that facilitate worker through instructions about the sequence of operations, components position, necessary tools for the product assembly [18]. The authors conclude that the system is effective, because the assembly tasks are performed in more efficient way and the risks of musculoskeletal disorders are reduced.

IV. AUGMENTED REALITY IN ENGINEERING EDUCATIONAL PROCESS

The educational process includes basic activities such as teaching, learning and assessment. The aims of the teaching tasks are the course syllabus and learning/instructional/assessment materials to be prepared, new knowledge to be introduced and students' achievements to be evaluated. The teacher can be placed in the role of learning designer, knowledge provider, learning facilitator, moderator, and evaluator. The learning process involves students in a wide variety of activities – from reading and writing to more compelling and interactive, motivational and engaging tasks. The assessment proposes methods for students' attitudes, knowledge and skills evaluation and also could be used in support of teaching and learning.

AR as technology enhancing engineering educational process is accepted for improvement of teaching, learning and assessment in several directions according to the examined scientific publications. Yuen et al. see the following areas for AR implementation in education: AR books, AR gaming, discovery-based learning, objects modeling and skills training, helping teachers to present difficult-to-understanding topics, contributing to improvement of students' experience, stimulating students' creativity, giving possibilities to students to manage their own learning, and facilitating learning through different learning styles [19].

Rizov and Rizova explore the application of AR technology in teaching practice as a didactic tool [20]. The experiment is performed with students involved in the course "Engineering graphics" in several technical faculties. The AR system is based on BuildAR application from HITLAB and the ARToolKitPlus algorithm. The findings show that the results are remarkable. According to teachers' opinion the AR solution improves the display of teaching material and its delivery in more interesting way, contributes to easier knowledge transfer and to time saving in lecturing. A big part of the students agrees that teaching with AR leads to better understanding of course material and understanding the learning material in short time, contributes to passing the course and to high results from the skills tests.

Liarokapis and Anderson summarize the benefits of AR technology for higher education to: multi-modal presentation of teaching material that is difficult for understanding, exploration and interacting with the AR teaching material, collaboration and discussion [21]. The experiments are conducted in two pilots at teaching in three courses: "Introduction to Information Technologies", "Virtual Environments" and "Multimedia". The students' opinion is gathered and they describe AR technology as very promising for teaching, pointing out its advantages for easy understanding of theories and concepts, for facilitation the collaboration between the lecturer and the students, for receiving rich visual experience in an interactive way.

Juan et al. are implemented an interactive teaching system using AR mobile technology through usage of Unity 3D software, Android SDK and Vuforia SDK [22]. The system is used in the course "Mechanical Drawing" and its aim is to improve the students' understanding about the mechanical parts, to improve the drawings reading, to facilitate the perception of sophisticated structures, to assist students in drawing in different views, to improve understanding of the teaching material, to support students in problem solving after classes. The students are surveyed and also their performance is evaluated. The conclusion is that the proposed system increases the students' interests to learning, enhances their imagination capabilities and improves their academic record.

Hedberg et al. are performed a systematic review about usage of mobile AR technology in learning [23]. The findings reveal that the AR influences positively on the learning outcomes and leads to improvement of students' motivation, engagement, collaboration, creativity, problem-solving skills and study results. The applied learning strategies are focused on organizing interactive learning, inquiry-based learning, collaborative learning, immersive learning, game-based learning, multi-modal learning, informal learning and constructivist learning.

Ibáñez et al. demonstrate the usefulness of AR technology for construction of students' practicing assessment activities [24].

Sánchez et al. in the implemented hand-held AR system, designed for educational purposes in the area of architecture, civil and building engineering, assess the students' performance who had to work with complex virtual objects [25]. The findings show significant improvement in the overall learning performance of students

V. META-MODEL FOR APPLYING OF AR TECHNOLOGY IN CAD/CAM PROCESS AND ENGINEERING COURSES

In (figure 2), the authors present their meta-model for AR technology implementation which summarizes the results of the performed review. The first part describes the AR technology usage in CAD/CAM process for design and manufacturing of products. It can be said that many stages are supported by AR for documentation, presentation and experimentation. The second part explains the usage of AR technology in engineering education. An AR-based eLearning system should possess features for teaching, learning and assessment through usage of AR web-based, mobile-based or combined technologies. The summarized knowledge about facilitation of activities in CAD/CAM process through AR will be used for educational purposes and delivered also with AR technology.

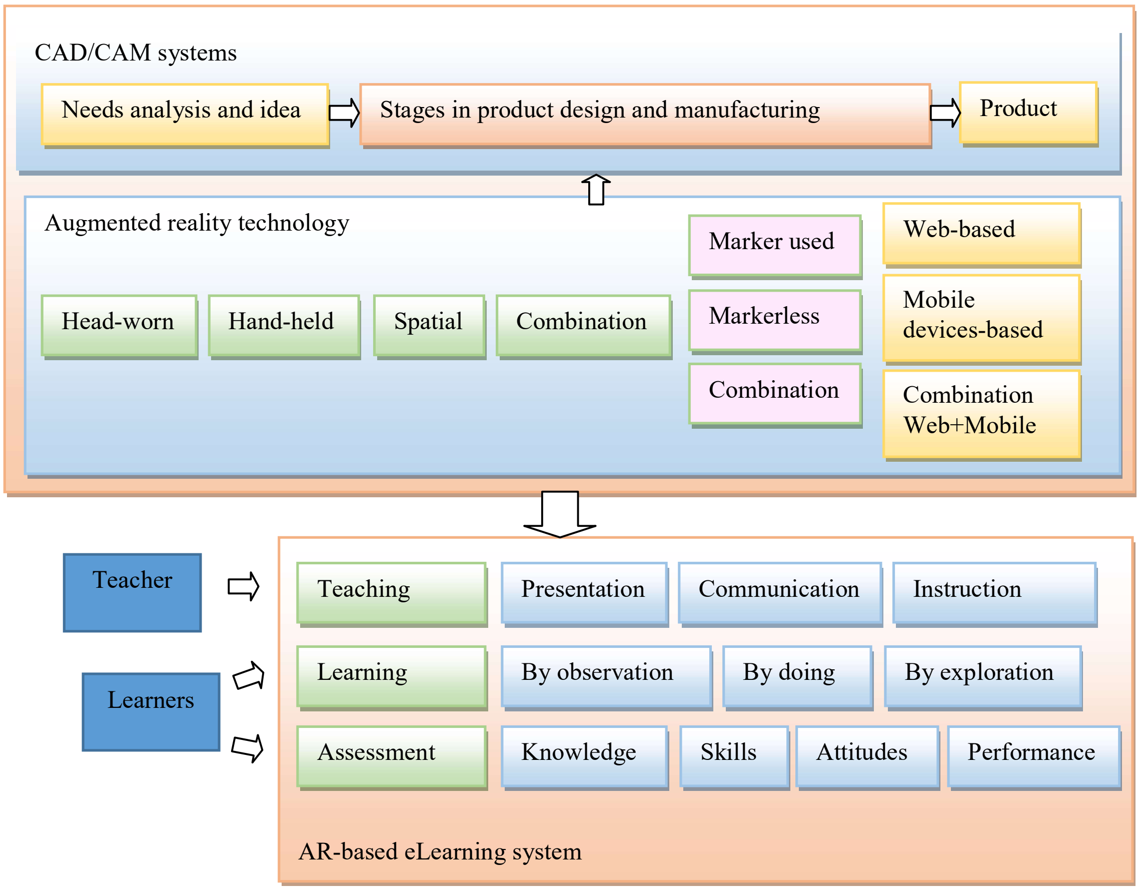

Figure no. 2. Meta-model for AR usage in product design and manufacturing and in engineering education

VI. CONCLUSIONS

The paper presents summarization and analysis regarding the role of AR technologies in different stages of CAD/CAM process. It can be said that AR could support nearly all the tasks typical for product design and manufacturing. In the same way it helps companies to reduce their costs and time at launching new products, to improve team working for their office-based and remote teams, and to visualize problems, creating virtual prototypes, before they occur in the real world.

It can be seen that the AR technology not only facilitate the engineering process, but also this is a very useful method in an educational context. Teaching and learning CAD/CAM systems through

AR leads to several benefits for teachers and students. Teachers have possibility to present and discuss topics in more engaging and attractive way, while students can not only passively perceive digital information, but also they could be actively involved in creation and interactions with 3D learning objects.

The knowledge concerning how AR technologies are used in CAD/CAM systems could be applied in teaching/learning processes and also could be facilitated through AR that is shown through development of a meta-model for AR usage in product design and manufacturing and in engineering education.

Reference Text and Citations

[1] Julie Carmigniani and Borko Furht, Chapter 1 *Augmented Reality: An Overview*, B. Furht (ed.), Handbook of Augmented Reality, doi: https://doi.org/10.1007/978-1-4614-0064-6, Springer Science+Business Media, LLC 2011, 3-46.

[2] D. W. F. van Krevelen and R. Poelman, 2010. *A Survey of Augmented Reality Technologies, Applications and Limitations*. The International Journal of Virtual Reality, 9(2), 1–20.

[3] Bernard Marr (Contributor), 2019. *5 Important Augmented and Virtual Reality Trends for 2019 Everyone Should Read*, https://www.forbes.com/sites/bernardmarr/2019/01/14/5-important-augmented-and-virtual-reality-trends-for-2019-everyone-should-read/#5963f8fc22e7

[4] Andrew Makarov, 2019. *9 Augmented Reality Trends to Watch in 2020: The Future Is Here*, MobiDev, https://mobidev.biz/blog/augmented-reality-future-trends-2018-2020

[5] Video and Optical See through Augmented Reality Surgical Systems project, https://www.vostars.eu/

[6] Intuitive Self-Inspection Techniques project, https://www.insiter-project.eu/en

[7] Digital Innovative Media Publishing for All project, http://www.dimpaproject.eu/

[8] Bernhard P. Bettig, *Introduction to CAD*, http://community.wvu.edu/~bpbettig/MAE455/Lecture_1_CAD_intro.pdf

[9] Kiran Kumar Kudumula, *Computer Aided Design and Manufacturing Notes*, https://www.academia.edu/20401700/COMPUTER_AIDED_DESIGN_AND_MANUFACTURING_NOTES_by_kiranmedesign_at_gmail.com

[10] Juan C. Arbeláez-Estrada and Gilberto Osorio-Gómeza, 2013. *Augmented Reality Application for Product Concepts Evaluation*, Procedia Computer Science, vol. 25, 389 – 398.

[11] A. E. Uva, M. Fiorentino, and G. Monno, 2011. *Augmented Reality integration in Product Development*, Proceedings of the IMProVe 2011 International conference on Innovative Methods in Product Design June 15th–17th, 2011, Venice, Italy, 73-79.

[12] Pedro Santos, Holger Graf, Timo Fleisch and André Stork, 2003. *3D Interactive Augmented Reality in Early Stages of Product Design,* Proceedings of the 10th International Conference on Human-Computer Interaction, vol.4, Inclusive Design in the Information Society, Mahwah/NJ.: Erlbaum, ISBN: 0-8058-4933-5, 1203-1207.

[13] Lorenzo Giunta, Elies Dekoninck, James Gopsill and Jamie O'Hare, 2018. *A Review of Augmented Reality Research for Design Practice: Looking to the Future,* Proceedings of NordDesign 2018, August 14th – 17th, Linköping, Sweden, https://www.designsociety.org/publication/40967/A+Review+of+Augmented+Reality+Research+for+Design+Practice%3A+Looking+to+the+Future

[14] Jozef Novak - Marcincin, Jozef Barna, Veronika Fecova and Ludmila Novakova - Marcincinova, 2012. *Augmented Reality Applications in Manufacturing Engineering*, Proceedings of the 23rd International DAAAM Symposium, 23(1), 65-68.

[15] Daniel Segovia, Miguel Mendoza, Eloy Mendoza and Eduardo González, 2015. *Augmented Reality as a Tool for Production and Quality Monitoring*, Procedia Computer Science, vol. 75, 291 – 300.

[16] F. Doil, W. Schreiber, T. Alt and C. Patron, 2003. *Augmented reality for manufacturing planning*, Proceedings of the Workshop on Virtual Environments, Zurich, Switzerland, 71-76, doi 10.1145/769953.769962.

[17] Ammar Malika, Hugo Lhachemi, Joern Ploennigs, Amadou Ba and Robert Shorten, 2019. *An Application of 3D Model Reconstruction and Augmented Reality for Real-Time Monitoring of Additive Manufacturing*, Procedia CIRP, vol. 81, 346–351.

[18] Maura Mengoni, Silvia Ceccacci, Andrea Generosi and Alma Leopardi, 2018. *Spatial Augmented Reality: an application for human work in smart manufacturing environment*, Procedia Manufacturing, vol. 17, 476–483.

[19] Steve Chi-Yin Yuen, Gallayanee Yaoyuneyong and Erik Johnson, 2011. *Augmented Reality: An Overview and Five Directions for AR in Education,* Journal of Educational Technology Development and Exchange, 4(1), Article 11, 119-140.

[20] Tashko Rizov and Elena Rizova, 2015. *Augmented Reality as a Teaching Tool in Higher Education*, International Journal of Cognitive Research in Science, Engineering and Education, 3(1), 7-15.

[21] Fotis Liarokapis and Eike Falk Anderson, *Using Augmented Reality as a Medium to Assist Teaching in Higher Education*, https://core.ac.uk/download/pdf/16497877.pdf

[22] Juan Cheng, YuLin Wang, Dian Tjondronegoro and Wei Song, 2018. *Construction of Interactive Teaching System for Course of Mechanical Drawing Based on Mobile Augmented Reality Technology*, International Journal of Emerging Technologies in Learning, 13(2), 126-139.

[23] Hillevi Hedberg, Jalal Nouri, Preben Hansen and Rahim Rahmani, 2018. *A Systematic Review of Learning through Mobile Augmented Reality*, International Journal of Interactive Mobile Technologies iJIM, 12(3), 75-85.

[24] María-Blanca Ibáñez, Diego Villarán and Carlos Delgado-Kloos, 2015. *Integrating Assessment into Augmented Reality-Based Learning Environments*, Proceedings of IEEE 15th International Conference on Advanced Learning Technologies, 6-9 July 2015, Hualien, Taiwan, 218–222.

[25] Albert Sánchez, Ernest Redondo, David Fonseca and Isidro Navarro, 2014. *Academic performance assessment using Augmented Reality in engineering degree course*, Proceedings of IEEE Frontiers in Education Conference, 22th-25th October 2014, Madrid, Spain, doi:10.1109/FIE.2014.7044238.