XR Technologies in Mechanical Engineering Education

Published Version:
De Crescenzio, F., Tassinari, M.E., Frizziero, L., Liverani, A., Marcuccio, M. (2025). XR Technologies in Mechanical Engineering Education. Cham : Springer [10.1007/978-3-031-76594-0_48].

Availability:
This version is available at: https://hdl.handle.net/11585/1005231 since: 2026-02-05

Published:
DOI: http://doi.org/10.1007/978-3-031-76594-0_48

XR Technologies in Mechanical Engineering Education

Francesca De Crescenzio[1], Maria Elena Tassinari[2], Leonardo Frizziero[1], Alfredo Liverani[1] and Massimo Marcuccio[2]

[1] Industrial Engineering Department, University of Bologna, Bologna, Italy
[2] Education Studies, Giovanni Maria Bertin" Department, University of Bologna, Bologna, Italy
francesca.decrescenzio@unibo.it

Abstract. Manufacturing industries today are undergoing a formidable process of transition to completely new and sometimes unfamiliar modes of operation. This process is also known as the 5th Industrial Revolution and involves the implementation of a set of technologies including, among others, digital technologies such as XR-Extended Reality, AI, Big Data and Digital Twins. In particular, Extended Reality, which encompasses the full spectrum of advanced 3D models and techniques for visualizing and interacting environments, is already a standard *de facto* method at some stages of the product life cycle. In the design phase of complex systems, for example, it supports designers, other business functions and end users in the collaborative analysis of complex assemblies. While these technologies are supported as enablers for the aforementioned transition in industries, their use at the academic level remains focused on the goal of creating more interactive educational experiences and enhancing understanding of complex concepts. In contrast, this paper analyzes the use of XR in mechanical engineering curricula with the goal of identifying the main challenges for creating advanced digital skills for engineers and empowering them to integrate such knowledge into industrial process optimization. The results of a focus group with students in the Master of Mechanical Engineering program reveal the need to support young people in understanding the benefits of using such technologies in their work.

Keywords: Extended Reality, Engineering Education, Mechanical Engineering, Focus Group

1 Introduction

When the Industry 4.0 paradigm was firstly introduced, it was based on a set of technologies indicated as enablers for a totally different concept of industry. The main drivers of Industry 4.0 were identified in digitization, intelligence and virtual interconnection between systems and remote subsystems and components [1]. Augmented Reality (AR), the technology based on computer-generated overlays that support operators in performing safer operations in real settings, was one such technologies. On the other hand, Virtual Reality (VR) had already been proposed in a number of industrial applications and products ranging from design support, overhaul, and lifecycle management [2]. The difference and peculiarities of AR and VR have been firstly identified and defined by Paul Milgram, that conceived the so called Reality-Virtuality continuum [3]. In a VR world, everything moves from a physical base to an immaterial world and, in some cases, makes machines completely autonomous. Only a few years later, the community came to the conclusion that machines cannot work alone and realized that human-centeredness is one of the most important properties that every design activity must consider to ensure the sustainability of society. This is one of the pillars of what has been called the 5th Industrial Revolution [4]. The challenge now is how to make humans capable of interacting in their daily lives with such a large amount of data and data formats and improve the overall performance of operations while ensuring the well-being of citizens. Meanwhile, technologies and market for display devices have dramatically evolved into a world of options that cannot be limited to Augmented Reality and Virtual Reality, and this evolutionary trend is so strong that a new term has been coined to include Augmented Reality, Virtual Reality, Mixed Reality, and even what does not yet exist: Extended Reality (XR). Under these conditions, industries and academies have begun to implement research and innovation programs based on the use of XR, which in many cases are already part of industrial processes [5][6].

With this in mind, it is easy to see that future mechanical engineers must have skills in XR, as they will need to be prepared to experience industrial contexts in which these technologies will be used intensively. One of the main issues in this process is related to the cultural perception of the figure of mechanical engineers. The scope of this paper is i) to investigate the actual perception of mechanical engineering students towards XR technologies and ii) propose recommendations for the digital transition of tools and methods in academic engineering. Hence, with the goal of better understanding how to implement the introduction or adaptation of these skills into engineering curricula, a study was conducted with master's students in Mechanical Engineering at the Forli Campus of the University of Bologna. This study is part of the Augmented Alma University Project. Augmented Alma is a project conducted at the University of Bologna involving Head of Departments and Professors from various disciplines with the aim of valorizing and improving current experiences and generating new training opportunities to learn more about the use of immersive technologies for learning purposes [7]. The exploratory study described in this paper is based on the organization of a focus group with students. The focus group is part of a co-designed research activity to understand how the students participating in a specific course, the Product Design Laboratory activated in the academic year 2022/23, interpreted the activity carried out and to gather suggestions from them to develop and improve the teaching intervention. Section 2 introduces the concept of XR and its applications in Industrial Engineering (Section 2.1) and in Mechanical Engineering curricula (section 2.2). Section3 illustrates the materials and methods. Finally, results of the focus group are presented in Section 4.

2 XR in Engineering Education

2.1 XR applications in Industrial Engineering

In the field of industrial engineering, where efficiency, safety and precision are paramount, the integration of cutting-edge technologies has always been a driving force for progress. Among these technologies, Extended Reality (XR) stands out as a transformational tool with immense potential to revolutionize traditional industrial processes. XR, which includes Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR), offers immersive and interactive experiences that blur the boundaries between the physical and digital worlds.

The application of XR technologies in industrial engineering is poised to redefine the way activities are conceptualized, executed and optimized in various sectors. From manufacturing to logistics, quality control to training, XR presents a myriad of opportunities to increase productivity, reduce costs and improve overall operational efficiency. In [8] virtual reality environments are used to implement user-centered design methods in the design of innovative aircraft cabin interiors. Moreover, Doolani et al. present an extensive review of XR for training in manufacturing, identifying different phases of training where XR can be successfully applied and also other training contexts, such as medical training [9]. By leveraging XR, industrial engineers can visualize complex systems, simulate environments and interact with digital models in previously unimaginable ways.

The systematic review by Álvarez-Marín et al. [10] shows that AR in education has been well-received by students, resulting in increased engagement, participation, and interest. The technology is perceived as useful, leading to improved test performance and serving as a valuable tool for self-directed learning and self-evaluation. Nevertheless, usability is a key consideration in AR education, but there have been criticisms related to educational and technical aspects. Some students struggle to follow an instructor's explanation while using an AR app and learning new concepts without support, highlighting the need for a solid theoretical foundation. However, these criticisms are specific to certain AR apps, and collaborative approaches to AR have been reported to be successful. Technical usability issues include stability problems, screen flickering, and lag when manipulating virtual models.

2.2 XR applications in Mechanical Engineering curricula

The importance of integrating extended reality (XR) technologies into mechanical engineering curricula has been increasingly recognized in recent years. XR offers unique opportunities to enhance the learning experience, provide hands-on training, and prepare students for the challenges of modern engineering practice. One possible outcome of such integration may be the enhancement of visualization and conceptualization activities that are specific to mechanical engineering and are often put into practice in modern universities. To this end, XR technologies enable students to visualize complex mechanical systems in three dimensions, facilitating a deeper understanding of concepts such as machine design, kinematics and dynamics. By immersing students in virtual environments, XR allows them to interact with digital models and manipulate them in real time, fostering spatial awareness and problem-solving skills. In [11] the author demonstrates that "*VR and 3D prototyping in the context of project-based learning (PBL) promote effective communication, increase problem solving skills, and enhance learning outcomes*".

In addition, XR enables interactive learning experiences by simulating real-world scenarios. For example, VR simulations can be used to teach concepts related to machining, assembly processes, and material properties, allowing students to practice skills in a safe and controlled environment. Similarly, AR applications can overlay digital information onto physical objects, enabling students to explore mechanical components and systems in situ. In [5] researchers from the Department of Mechanical Engineering and Aeronautics of the University of Patras (Greece) describe an Hybrid teaching factory model based on Extended Reality. Furthermore, XR technologies offer hands-on training opportunities that complement traditional laboratory exercises and theoretical instruction. For instance, VR-based training modules can simulate equipment operation, maintenance procedures, and troubleshooting techniques, allowing students to develop practical skills without the need for physical prototypes or machinery. An example of such virtual laboratory is presented in [12] where the architecture of a Mixed Reality framework is described and use cases, such as collaborative robots environments, are presented together with future perspectives. Additionally, AR-enabled remote assistance tools can provide real-time guidance and support to students performing technical tasks in the field or laboratory. XR can also facilitate collaborative design and prototyping activities among mechanical engineering students by enabling real-time visualization and manipulation of digital prototypes. MR environments, in particular, allow multiple users to interact with virtual models simultaneously, fostering teamwork, communication, and creativity. By working together in immersive virtual spaces, students can iterate on designs, evaluate performance, and identify potential improvements more effectively than traditional methods. Finally, integrating XR into mechanical engineering curricula, helps to prepare students for careers in industries where these technologies are increasingly being adopted. By gaining hands-on experience with XR tools and applications, students develop valuable skills in digital design, simulation, data visualization, and human-computer interaction—skills that are highly sought after by employers in fields such as manufacturing, aerospace, automotive, and robotics. In this view Berglund proposes the use of Design for XR guidelines to be thought in Design and Engineering curricula also to develop projects highlighting the advances in sustainability given by digital interfaces [13].

Overall, incorporating XR into mechanical engineering curricula holds great promise for enriching the learning experience, fostering innovation, and equipping students with the skills they need to succeed in the rapidly evolving field of engineering. This concept is strengthen by an extensive literature review proposed by Alnagrat et al.,

that also gives suggestions for future development introducing concepts such as "Virtual Environment of things" [14] As educators continue to explore and embrace these technologies, it is essential to consider factors such as accessibility, scalability, and pedagogical effectiveness to ensure that XR-enhanced learning experiences are inclusive, engaging, and impactful for all students.
Among the other courses, some of the Courses in Mechanical and Naval Engineering at the University of Bologna implementing XR are: Vehicle Virtual Design, Computer Aided Design and Naval Engineering and Design and Design Methods for Industrial Engineering. In these courses, the adoption of XR allows students to better learn the subject with the possibility of interacting with digital prototypes of the systems created.

3 Materials and Methods

The Product Design workshop is a course structured in three parts of learning and practice. The first part is based on exercises in reverse modelling and 3D printing of complex objects. Students started by selecting a case study through a bibliography of journal articles dealing with additive manufacturing and biomimetic shapes. During this phase, students practiced free-form NURBS 3D modelling functions with Rhinoceros 7 and FDM (Fused Deposition Modelling) with soluble support 3D printers such as Stratasys Fortus 250 mc and Stratasys Object 30 Prime . In groups of 2, students had to model the shape, select the printer, set the printing parameters, follow the printing process, and perform post-processing. The post-processing phase consisted of removing the support material.
In the second phase, students practiced with Virtual Reality and Augmented Reality. First, they participated in a demonstration activity at the Virtual Reality Lab to understand the operating principles of VR and AR devices such as Oculus Quest 2 and Microsoft Hololens. Then they were introduced to Unity 3D software. Unity is the de facto standard for developing Virtual Reality applications on various devices. Currently, developing applications with Unity still requires programming skills. However, the trend is toward user interfaces that allow non-programming-savvy users to develop their own applications. At the basic level, students learn how to build a virtual scene populated by their 3D models and connect it to a physical marker to create an augmented reality prototype (**Fig. *1***). The goal is for them to understand how CAD models, which engineering students have already used to create and manipulate in desktop interfaces, can become real interactive models and be integrated into a real environment.

Fig. 1 Students during the Augmented Reality workshop

During the third phase, students are asked to develop and present a personal project based on devising an opportunity to apply Augmented or Virtual Reality either in the manufacturing industry or in other contexts related to their personal experiences.
At the end of the course the students have been involved in two meetings held in the form of focus groups on May 31st 2023 at the Forlì Campus. In total, there were 13 participants divided into two groups: the first composed of 7 male students; the second by 6 students (1 female and 5 male). One of the authors conducted the focus groups [15],[16], each lasting about an hour; a second one served as an observer. The audio recordings of the two meetings – made after the students gave informed consent – were transcribed and analyzed through thematic content analysis [17],[18].

4 Results

The students participated actively and with interest in both focus groups. The question about a possible future professional outlet inherent in the use of virtual and augmented reality has aroused the same answer in almost all the students. In general, there was no perception of immediate usefulness linked to their professional profile. Nevertheless, everyone has shown interest and curiosity in the use of these new technologies. A student mentioned that: "The activity is part of our areas but it is not the most typical thing, that is, probably none of us will go to do it when we leave here (...) Because our figure of mechanical engineers in industry refers to a field that does not entirely concern these technologies: at least not entirely. It is also true that this workshop is only a few hours long (30 hours and therefore 3 credits). But if you get passionate, take the plunge, taking other courses, you could specialize in these things and in my opinion you could find a job right away."
The laboratory activity was scheduled after the performance of a theoretical teaching of 60 hours in which all the concepts, constructs and procedures that would be opera-

tionally useful during the laboratory phase were explained. In view of this, almost all of the students considered it essential to attend the theoretical course in order to be able to carry out the laboratory in the best possible way: "The main theoretical course was mainly based on Rhino3D. Instead, in the workshop there was a refresher on drawing and then a lunge on Virtual Reality. So it was a continual: (...) in the first one more theory and in the second we put more into practice". And again: "Perhaps [the workshop] could have been done without the theoretical part, but certainly many open questions remained (...) Things would have been done without probably understanding why they were being done."

Another fact that emerged in both groups is the identification of Virtual Reality as a useful tool to be able to enter more into the practical and operational part. In fact, one student said: "I found it interesting personally, because we applied what we saw in the last semester only in having identified virtual reality as a useful tool to be able to enter more into the practical part and theoretical form." And again: "I probably would have liked this mode of application to be present in other courses as well because you never get your hands on things.

After the use of AR and VR by the students, they were asked if these tools could help and improve the learning process. Some of them stated that these new technologies could in some cases represent a help "for the university... because it is in any case a tool that serves to make more things more usable and understandable to anyone (...)" and again "with these means it would be more understandable to understand the professors' speeches, with (...) however a little help of this kind to establish theoretical concepts could be a significant help for the student".

Other students instead proposed a distinction based on the object to be learned: "It's true, it can help you... but the formulas are there, the theory is there (...). So yes, it can help you with many things but in my opinion in the short term it won't totally change the way we teach and learn, at least in our field." Another student stated: "As long as it concerns things like physics, where simulation is possible (…) it's fine! When it comes to mathematics, analysis, formulas (...) I don't know how I could help out through virtual reality."

At the end of the focus groups, suggestions for improvement were made by the students; some of them proposed that the hours of explanation of the Unity software be increased; others requested the availability of a greater number of devices so that they could be used for a prolonged time and without the need for shifts.

5 Conclusions

An experimental study on the use of XR as part of mechanical engineering curricula has been presented. The study has been based on focus groups conducted at the end of a practical course integrating XR in the teaching syllabus. A set of recommendations arose from the focus group. Firstly, from the analysis of what emerged within the focus groups, it is interesting to understand how almost all students feel the need to increase practical activities to be associated with theoretical explanations.

A further aspect that emerged is the students' perception of VR and AR activities as not strictly functional to their future work environment. This can be interpreted as a manifestation of a weak prospective vision of students with respect to the world of work but also a conception of the university that is strictly functional to the current job market. In fact, one of the main tasks of the university is to prepare students for innovation in work and study contexts. In this sense, the university has the task of preparing agents of change, that is, students capable of being the promoters of changes in work contexts and not only knowing how to reactively welcome them when they arise induced by the context. Unfortunately, this conception of education for the here and now (*hic et nunc*) is very widespread among students of all fields. It is therefore necessary for the university to help students - with adequate strategies - so that they develop a new concept of their being at university, projecting themselves into the future in an active and conscious manner, capable of conceiving themselves personally as agents of innovation within the different professional realities. This, from a pedagogical point of view, firstly implies making this aspect explicit and continuously clear to students in such a way as to provide them with the keys to adequately interpret the training proposals they receive.

All these recommendations in mind, the future work will consist in the development and testing of further innovative teaching activities based on the use of XR in collaboration with all the Mechanical Engineering disciplines in order to better understand the benefits brought, the limitations and foster the process of digitalization of academic curricula.

References

1. Lasi, H., Fettke, P., Kemper, H. G., Feld, T., & Hoffmann, M., Industry 4.0. Business & information systems engineering, 6, 239-242 (2014).
2. Cardenas-Robledo, L. A., Hernández-Uribe, Ó., Reta, C., & Cantoral-Ceballos, J. A. Extended reality applications in industry 4.0.–A systematic literature review. Telematics and Informatics, 73, 101863 (2022).
3. Milgram, P., Takemura, H., Utsumi, A., & Kishino, F., Augmented reality: A class of displays on the reality-virtuality continuum. In Telemanipulator and telepresence technologies Vol. 2351, 282-292 (1995).
4. https://research-and-innovation.ec.europa.eu/, last access 2024/03/25.
5. Mourtzis, D., Angelopoulos, J., & Panopoulos, N., Extended reality (xr) applications for engineering education 5.0. Proceedings of the 13th Conference on Learning Factories (CLF 2023) Available at SSRN 4470086 (2023).
6. di Lanzo, J. A., Valentine, A., Sohel, F., Yapp, A. Y., Muparadzi, K. C., & Abdelmalek, M. A review of the uses of virtual reality in engineering education. Computer Applications in Engineering Education, 28(3), 748-763 (2020).

7. Augmented Alma — Teaching and Learning Centre (unibo.it) (https://centri.unibo.it/teaching-learning/en/other-initiatives/augmented-alma), last accessed 2024/04/28.
8. De Crescenzio, F., Bagassi, S., Asfaux, S., & Lawson, N. Human centred design and evaluation of cabin interiors for business jet aircraft in virtual reality. International Journal on Interactive Design and Manufacturing (IJIDeM), 13, 761-772 (2019).
9. Doolani, S., Wessels, C., Kanal, V., Sevastopoulos, C., Jaiswal, A., Nambiappan, H., & Makedon, F. A review of extended reality (xr) technologies for manufacturing training. Technologies, 8(4), 77 (2020).
10. Álvarez-Marín, A., & Velazquez-Iturbide, J. A. Augmented reality and engineering education: A systematic review. IEEE Transactions on Learning Technologies, 14(6), 817-831 (2021).
11. Halabi, O. Immersive virtual reality to enforce teaching in engineering education. Multimedia Tools and Applications, 79(3), 2987-3004 (2020).
12. M. Hoffmann, T. Meisen, und S. Jeschke, Shifting Virtual Reality Education to the Next Level–Experiencing Remote Laboratories through Mixed Reality, in Proceedings of the International Conference on Computer Science, Computer Engineering, and Education Technologies (CSCEET2014), Kuala Lumpur, Malaysia, 17-19 November 2014, (2014).
13. Berglund, A., Design for extended reality (DfXR)–Exploring engineering and product design education in XR. In DS 123: Proceedings of the International Conference on Engineering and Product Design Education (E&PDE 2023) (2023).
14. Alnagrat, A. J. A., Ismail, R. C., & Idrus, S. Z. S. Extended reality (XR) in virtual laboratories: A review of challenges and future training directions. In Journal of Physics: Conference Series (Vol. 1874, No. 1, p. 012031). IOP Publishing (2021).
15. Zammuner, V. L. I focus group. Bologna: il Mulino. (2003).
16. KRUEGER, Richard A. *Focus groups: A practical guide for applied research*. Sage publications, (2014).
17. Alivernini, F., Lucidi, F., & Pedon, A. L'analisi qualitativa del contenuto. In F. Alivernini, G. Lucidi, & A. Pedon, Metodologia della ricerca qualitativa, Bologna: il Mulino, 89-105 (2008).
18. Cataldi, S., Come si analizzano i focus group. Milano: FrancoAngeli. (2009).