Incorporating Extended Reality technology for delivering Computer aided Design and visualisation modules

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**Abstract**—The basic requirement in curriculum design is to review and constructively align programme modules with state-of-the-art trends in the subject area. Extended reality (XR), an umbrella term for emerging technologies such as augmented reality (AR), mixed reality (MR) and virtual reality (VR), is becoming a prominent aspect of design and visualization for architecture, engineering, and construction (AEC) industry. Engineering programmes are primary feeders for the AEC industry, delivery of CAD and visualisation modules provide wider opportunities for adapting such emerging technologies in the subject area, as well as use of these technologies for developing novel pedagogical practices. This paper provides a rational behind revising traditional CAD and visualisation modules designed for Engineering undergraduate programmes, and constructively incorporate XR within programme modules. A critical literature review is provided on XR subject area as well as XR based pedagogical practices. This review identifies elements of XR as a subject area that can be incorporated in AEC programmes. It also highlights academic and operational considerations in adapting XR technology for delivering CAD and visualisation modules. Similar approach is extended to evaluate integration of XR technologies for Electrical and Power Engineering Programmes.

**Keywords**—Extended Reality, XR, Virtual reality, Computer aided Design, CAD, Power Engineering, Higher Education, Pedagogy

I. INTRODUCTION

The current state of XR results from cross-disciplinary advancements in disciplines such as computer graphics, human-computer interaction, psychology, computer games technologies, electronics, optics, physics, and sensory communication. XR as a subject can be classified into two areas, applications and technology development. Although these areas complement each other, they present subtle differences in required underpinning knowledge and skill prerequisites. The application area for XR is mainly concerned with developing software and using the current state of XR technology for various mainstream applications, such as AEC (which includes Mechanical, Aerospace, Automotive, CAD/CAE sectors) training, entertainment, cultural heritage, and education. Whilst the XR technology development area is focused on advancement of hardware and low-level software applications that support the development of new XR technologies [1]. This paper focuses on the former subject area, applications, and in particular, on the application of XR to CAD and visualization in higher education.

Academic literature and industrial case studies [1, 2] provide many examples of XR applications for education. However, Häfner et al. [3] report that there is an XR knowledge and skills deficit in current students graduating from Mechanical and AEC programmes. To ensure that Mechanical and AEC graduates have the skills required to join the industry 4.0, it is imperative to fill this knowledge gap by introducing XR into relevant undergraduate (UG) courses. Responding to this knowledge deficit and to fill the skills gap in recent graduates and current employees, many AEC industries are providing continued professional development (CPD) programmes using XR for their employees, exposing them to critical aspects of the job in a virtual environment. Training in XR technologies benefit the AEC industry by immersing employees to situations that would be too hard or too costly to replicate in normal circumstances. For example, in the construction industry XR training can reduce accident, costs, and resource minimisation [4], in the aircraft industry maintenance of aircrafts and turbines can be simulated for training purposes [2, 5], and in the general AEC sector XR can also benefit project management [6], collaborative product development [7], and workspace analysis [8]. XR based pedagogical approaches are explored in the literature [3, 4, 9] to evaluate appropriate teaching learning and assessments (TLA) methodologies for delivering AEC themed Engineering programmes. Applications of XR technology for teaching Mechanical Engineering subjects are reported to be beneficial to TLA in higher education (HE) [10]. However, limited emphasis is given on the suitability of XR modules from computing degrees for Mechanical Engineering programmes. Pre-requisite knowledge and skill sets required for introducing XR in Mechanical Engineering programmes are not explored thoroughly in the literature.
Whilst it can be argued that XR in HE can be simply used as a tool to generate an experience for the students without the need for students to be able to develop the software, it can also be argued that this is not sufficient for Mechanical and AEC graduates, who need to be ready for industry 4.0 and, as such, need to acquire a new set of skills to deal with DARQ (Decentralised ledger, AI, extended Realities, Quantum computing) technologies. To achieve this, Mechanical and AEC students need to be both users of XR technologies and developers, creating XR experiences that fit the purpose of the industry they will be working in. This paper presents reflections on how to achieve the latter goal of enabling students to develop XR experiences.

This paper contributes to knowledge by providing insight to educators wishing to integrate XR development into Mechanical Engineering UG programmes. The paper provides academic considerations and a literature analysis on XR borrowing from existing creative computing modules, specifically from a Computer Games Development (CGD) programme.

II. LITERATURE REVIEW

The first half of this literature (section 2.1 and 2.2) provides commonalities and adaptiveness between CGD and Mechanical Engineering. This review highlights prerequisite knowledge and skills required in Mechanical Engineering programmes for adapting XR to the subject area. The second half of the literature review (section 2.3) explores XR based teaching, learning and assessment (TLA) methodologies.

A. Comparison of underpinning knowledge, skills and subject areas for Computer Games Development and Mechanical Engineering programmes

UG Mechanical Engineering or AEC programmes are typically designed to produce job-ready professionals with a breadth and depth of skills that prepare students for the modern workplace [11]. Broad knowledge and skills on subject areas within Mechanical Engineering programmes can include i) scientific principles, applications, and methodologies of mechanical engineering, ii) mathematical principles and models relevant to the subject area, iii) awareness of emerging ICT technologies and the ability to use computer-based engineering tools, iv) design processes, engineering principles, and methodologies, v) management and economic context of engineering processes and overall business perspective, vi) awareness of sustainability, legal frameworks, industry standards, health and safety, intellectual property and ethical aspects [12]. These knowledge areas provide overall expectations of UG Mechanical Engineering graduates by potential employers. In these knowledge areas, Mechanical Engineering students are expected to be aware of emerging ICT technologies and be able to use computer-based engineering tools. Motyl et. al. [13] highlights skill deficits in mechanical engineering student for adopting the industry 4.0 framework. Intellectual and practical skills expected form typical Mechanical Engineering (or AEC discipline) students are notably different to computing graduates with underpinning knowledge and skills in XR or games technologies development as inferred from Fig. 1.

Today, most universities offering BSc programmes in computing provide specialisation routes towards CGD. Broad knowledge, skills and subject areas within these specialised programmes can include i) computing architectures and networking systems ii) software engineering and programming paradigms iii) mathematical modelling for applied computing and games iv) computer graphics, real-time physics simulation programming v) 3D modelling and animation vi) Interaction design and user experience vii) motion capture, media, visual effect production viii) game engines. Figure 1 illustrates the knowledge areas spread and overlapping between a CGD programme and Mechanical Engineering programme. The blue arrows in figure 1 show areas of potential overlapping between subjects, whilst highlighted modules pertain to teaching XR technologies. The background knowledge required to understand appropriate use of XR and to develop useful experiences with the technology mixes a wide breadth of disciplines spanning from programming to the arts, including concepts from psychology and ergonomics.

Fig. 1. Knowledge areas in Computer Games Development and Mechanical Computer aided Engineering programme in a Scottish University. The Scottish University system comprises of a three years bachelor plus an Honours year, with entry points in year one, two, or three, depending on the UG student background.

B. XR technologies applications for ACE and Mechanical, CAD industry

Today, many AEC industries employ in-house rapid technology adaption programmes, where XR technology is explored for potential business cases. While reviewing XR applications in the field of aerospace application, Pirker [14] classified these use cases into virtual training and simulation, teleoperation, virtual testbeds, remote assistance and co-location, collaborative workspaces, design systems, mission planning, user studies and evaluations, therapy, and digital twins. Similar use cases are explored for Manufacturing and Product development applications [1], Design-Review, Failure Modes and Effects Analysis (FMEA), and criticality analysis (CA) [15], and architectural applications [6]. Most of these use-cases are developed by XR specialists. Skills and knowledge areas required to develop such applications are native to someone with creative computing background and expertise in XR or Games development. However, very few instances in literature on XR use-cases [1] provide details or
information on roles, knowledge, and background of the implementation team. This information can be useful for academic teams and educators who wish to introduce XR in relevant modules within AEC, CAD/CAE, and Mechanical Engineering UG programmes.

C. XR pedagogical approaches

Implementation of XR in HE has been gathering intensive attention due to proven benefits [16]. From the pedagogical point of view, XR lends itself to experiential learning [17], where students learn from concrete experience, reflective observation, abstract conceptualisation, and active experimentation [17]. This involves using XR to let students go through a series of specialised tasks designed to maximise learning of a specific subject, while being immersed within a contextual virtual environment that reflects working conditions of real-world industry, followed by reflections and group discussion activities, followed by sandbox experiments where students practice what they learned through experience. XR-based TLA methodologies have been proposed in the literature, such as [18], but most of these methodologies are influenced by learning outcomes of specific subject areas or the discipline [19].

Häfner et al. [3] proposed simulating interdisciplinary industrial projects for students from different disciplines to develop skills such as methodical approach to practical engineering problems, teamwork, working in interdisciplinary groups, and time management. Corresponding engagement with the project was 120 hrs (15 weeks). Students were introduced to the modelling tools such as Blender, CAD software like CATIA, and VR solutions like 3DVIA, before a group project was started. A similar project-based learning approach was proposed by Halabi [19] to design and implement a product using 3D design software. Their study found students can be self-directed in learning 3D modelling, animation, and texturing skills. Lee et al. [2] used VR base methods for aircraft maintenance practical educations, where video training methods were replaced with VR simulations. A VR environment and system was developed with Unity3D and C# scripts. The participants were trained for 18 min in VR environment for a specific aircraft maintenance task. Similar bespoke VR simulation lessons were developed by Liu et al. [20] for delivering science courses for sixth grade students. Instructors were trained on VR systems for 3 months before delivering proposed lessons. Root canal anatomy using VR environment was taught by Reymus et al. [21], where scaled tooth models were shown in VR; students were able to walk around for understanding anatomy. 360° VR videos were used by Sultan et al. for medical students [22] for delivering interactive lecture for 45 mins. A wound dressing exercise. Student training process, pre-requisite skills aspects and the specific tasks required to complete the exercise. Student training process, pre-requisite skills aspects were not discussed in the paper. Horne and Thompson [24] discussed integration process of early VR technology into Built Environment Education. They highlighted lack of academic resources, such as time and relevant expertise with school, for such cross-disciplinary subject integration projects.

Gilardi et al. [25] provides a detailed methodology (pre-design, design, and development phases) for identifying an appropriate pedagogy for XR, capturing student requirements, and integrating XR within teaching practice, highlighting challenges for developing bespoke XR solutions, which require a cross-disciplinary design team. From the student assessment point of view in XR there is little research on tools that can allow educators to review and provide feedback to students within the context of the XR simulations, with the most prominent work on the subject being Howie and Gilardi [26].

III. INCORPORATING XR TECHNOLOGIES FOR DELIVERING COMPUTER AIDED DESIGN (CAD) AND VISUALISATION MODULES

A. Identification of Learning Outcomes (LOs) and introduction of XR in a Mechanical Engineering programme

Underpinning knowledge and LOs of CAD/CAM/CAE modules can be compared with modules from CGD programmes as shown in Fig. 2 (revised from [27]).

Figure 2 illustrates academic progression of Mechanical Engineering students and few use-cases from underpinning subject modules. After reviewing relevant modules offered in UG CGD programmes, Figure 2 provide a list of skill areas and relevant LOs required for delivering illustrated use-cases through XR technology. Figure 2 also illustrates current provision in Mechanical Engineering programme to accommodate XR as a subject area for students. As students' progress through the UG programme, LOs become more focused on demonstrating applied knowledge of the subject area. Corresponding LOs in XR at lower levels (Figure 2) are more focused on re-using 3D modelling knowledge for building immersive environments. This can be achieved through introducing relevant XR aspects in existing modules such as CAD. Although, incorporating these LOs may have its own challenges [24], an appropriate pedagogical approach [24, 25] can provide pathways to implement such integration.

It can be seen from Figure 2 that modules for demonstrating practical skills and applied knowledge of XR may not be available in traditional Mechanical Engineering or AEC programme structures. Consequently, Year 4 LOs, which are focused on designing immersive experiences may not be achievable.

B. Integration approach

Adaption of the Computer aided Engineering (CAE) subject area in Mechanical Engineering or ACE programmes is conventionally delivered through specialist modules [24]. For example, Computer aided Design and Engineering modules include the use of dedicated CAD/CAM/CAE to achieve the intended LOs. As part of module delivery, students are introduced to CAD/CAM/CAE concepts and then given tutorials to use CAD/CAE software. Underpinning design concepts for Mechanical Design or Product Design can be visualised using this software. These design concepts can be visualised, analysed, and realised using knowledge achieved through CAD/CAM/CAE subject area. Before taking these modules, students are required to pass few pre-requisite modules or have prior knowledge (through employment) of this subject area, for example Technical
Typically, these modules are introduced in years 2 and 3 of the programme. This constructivist pedagogical approach to deliver CAD/CAM/CAE subject area has been providing opportunities to integrate advanced computer assisted technologies (such as cyber-physical systems, Industry 4.0, multi-CAD and cloud based collaborative design and development) within the curriculum. A similar constructivist approach for integrating XR can be adopted for updating Mechanical and AEC programmes. LOs outlined for year 2 and 3 provides a scope for integrating XR subject knowledge in existing CAD and visualisation related modules. A deployment strategy includes use of VR headsets and MR glasses during CAD laboratory session, use of dedicated XR software package for enabling students to collaborate and review CAD based designs and digital resources. This will help students to demonstrate use of XR technology. As a part of visualisation modules, existing storyboard development area can be amended to incorporate immersive experience. Thus, students will be able to storyboard interaction activities for immersive experience. Corresponding coursework can include (year 2/3) use-cases, as highlighted in Figure 2.

IV. DISCUSSION

A. Academic and operational considerations

Integration of XR technology in existing Mechanical or AEC programmes can be a step change for students as well as module delivery staff as immersive environments may use different resources (3D model types and software, Headsets and operating systems). Introducing XR technology requires use of XR hardware, such as AR mobile devices, MR glasses, or VR headsets. The benefits of introducing such technologies include improved engagement with the subject matter, exposure to situations that are dangerous if done in real life or simply not commonly possible in traditional Mechanical or AEC HE programmes, and remote collaboration in an immersive environment, making students and educators feel co-present in the same space, for instance during design reviews sessions. Operational challenges may include i) how this deployment can be achieved efficiently and effectively for large classes (i.e., more than 100 students)?; ii) what will be the effect of this change on different cohorts taking revised modules?; iii) staffing resources for integrating and delivering such subject area; iv) staffing resources for the maintenance of the XR hardware; v) access to hardware XR resources for students during independent study time and expectations from students to achieve XR related LOs; v) acceptance and experience from different gender, age, disability and backgrounds of students; vi) use of XR technology for delivering correspondence, transnational education (TNE) modules.

It must be noted that year 4 LOs associated with designing and implementing an immersive experience (Fig 2) can be challenging to achieve in Mechanical Engineering and AEC. Although scaffolding knowledge regarding “immersive interactivity” can be introduced in Year 3 visualisation modules using storyboard approach, implementing this knowledge using dedicated development tools such as Unity3D can be time consuming. Time required to develop relevant skills may require specialised modules that can be offered as an elective option in a typical Mechanical or AEC programme structure. Similar integration approach is exercised in incorporating CAD/CAM/CAE subject area in these programmes.

B. Deployment pathways towards other Engineering programmes through capacity building

Although this paper is focused on introducing XR related subject area for AEC and Mechanical Engineering programmes, other Engineering programmes such as Power Engineering, Electrical Engineering can also be benefited from XR applications. This paper provides an example of outlining and identifying discipline specific learning outcomes (LOs) for integrating XR in existing programme structure.
Some industries such as, the electrical Power Engineering (PE) industrial sectors are facing influx of new technologies [28]. Corresponding educational establishments are challenged with incorporating these technologies in education programmes due to significantly high capital investment and installation costs of resources. Consequently, similar to AEC industries PE industrial sectors have reported a deficit in a mechanism to update industry centric skills [29]. Health and safety (H&S) training within PE sector is of paramount importance. Knowledge, application, installation and use experience of these electrical and power equipment are expected from the wider employment market. However, the proprietary nature (e.g. Intellectual properties, Patents etc) of these businesses may limit academic access to these technologies. XR and CAD/PDM (Product Data Management) assisted technologies can provide a solution by controlling a level of exposure and access to new products and technologies in PE industrial sectors. For example, providing Power Engineering students a virtual field trip to power substation for explaining implementation new technologies and resources.

Deploying new PE technologies and associated knowledge in developing countries has been a challenge [29]. Access to modern, well-equipped PE laboratories is a prerequisite for the education of professionals attractive to the labour market. XR based pedagogy can provide an opportunity for developing countries to collaborated with universities in developed countries for transferring required knowledge, virtual experience, and skills in PE. Implementation of these technologies in developing countries can be done through Erasmus+ funded capacity building in Higher Education (CBHE) projects [30]. Use of XR application and technology for PE UG programmes may offer wider flow and transfer of new technology, skills and knowledge to developing countries. Development of distance learning using a specialised teaching platform would increase the availability and participation for these markets. Furthermore, it can provide education parity for disabled students in the teaching process and in the effectiveness of teaching. Similarly, students in remote locations, can benefit from this type of delivery.

However, integrating XR development in PE UG programmes may not be feasible as core modules in these programmes do not offer elementary CAD, 3D modelling, programming and visualisation subjects. Knowledge area mapping as shown in Figure 1 provides commonalities between Mechanical Engineering and CGD programme modules. Such overlap is not evident for PE programme modules. Thus, integrating XR modules in PE courses (year 2-4) may not be achieve corresponding XR based learning outcomes shown in Figure 2. Nevertheless, XR applications and pedagogical approach for delivering PE modules can be beneficial.

V. CONCLUSION

With the advent of industry 4.0, XR technologies are taking a prominent role within the AEC and Mechanical Engineering industries as well as in corresponding educational settings. XR technologies can make teaching and learning experience for students and staff more effective, but there are still many aspects of the use of the technology within the educational setting that need to be understood. This paper discusses LOs and an integration approach for incorporating the XR subject area in Mechanical and AEC programmes. A subject integration pathway has been proposed after reviewing relevant literature on XR based pedagogical approaches. Apart from various advantages for integrating XR subject area, significant gaps in achieving XR based LOs and operational challenges in restructuring above programme structures are identified through this paper. Similar requirement analysis for Power Engineering Programmes offers XR applications use cases, especially for delivering distance learning and TNE modules. However, integrating XR subject area and related modules in PE programme may not be feasible due to a lack of common knowledge, skill and subject area. Following conclusions can be drawn from the evaluation presented in this paper:

- XR applications in AEC and CAD, Mechanical Industry are increasing. Thus, UG students should have XR use experience embedded in the programme modules.
- AEC and CAD, Mechanical programmes may offer opportunity to include XR subject area in year 3-4 by introducing specialised XR modules, so students can develop XR immersive experience. Figure 1 and 2 provide overlapping areas.
- Electrical and Power Engineering (PE) programme students can be benefited from XR use experience embedded in the programme modules. However, integrating XR specialised modules in the programme may not be feasible as they do not take CAD, 3D modelling, Visualisation modules during Year 2-3.
- If UG students are to become industry 4.0 ready, the challenges outlined in this paper should be the focus of the education in Mechanical and AEC and Power Engineering research community.

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