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Immersive Virtual Reality in an Industrial Design Education Context: What the Future Looks Like According to its Educators

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Abstract. This paper presents and discusses the results of a future forecast study involving Higher Education educators from the field of industrial design and neighbouring. Participants were asked to imagine teaching and learning situations twenty years ahead, in a future where Virtual Reality (VR) technology and the design studio are harmoniously integrated. The aim was to project how the maturation of the technology and possible subsequent widespread adoption could affect design activity and design studio dynamics. While answering an online questionnaire, participants had to hypothesise uses or applications of the technology, the potential consequential behaviours derived from it and broader implications. Their answers hint at six areas where the technology is relevant to design. Behaviour wise, they envision students more engaged in research and creation, demonstrating a deeper level of knowledge over the variables influencing their projects and a proneness for collaborative or cooperative work. This change in dynamics contrasts with more cautious views who discern that a growing digital footprint weakens the relation with materials and sensibility development towards medium and process. These, combined with a lesser amount of real-world interactions, are perceived as undermining student maturity or growth. All of these and more hint at implications in the design process, pedagogy, curriculum, teacher and student dynamics and role repositioning, showing that integrating VR may have ramifications stretching far beyond the design studio context.

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1 OUTLINE

Virtual Reality (VR) has gained momentum in product design and development contexts in the last decades. Parallel to it and not always following similar paths, the technology has also experienced an uptake in research applications in Higher Education (HE) [18]. Between both, VR has provided sufficient proof of value as a tool for design activity, signalling that a broad adoption may lie somewhere on the horizon. Foreseeing such a future, some HE institutions have started to embrace the possibility by allocating funds to applied research and trialling different applications. Such initiatives, however, are not widespread, and many still dismiss the technology based on its relative infancy, unresolved issues (e.g., heavy system requirements, VR sickness, content availability), or unproven benefits towards teaching and learning. Notwithstanding, and as research and development continue, one persistent question gains relevance — how will the technology impact industrial design education?

Built around this question, the present study glimpses at possible futures scenarios in HE, where both VR technology and the industrial design studio are seamlessly integrated. It starts by reflecting on some of the most noticeable changes in HE learning environments today and the role technology played in it. From here, it moves onto the particular, placing focus on industrial design education and the influence technology has had on shaping both its curriculum and pedagogy. This point is reinforced by drawing parallels to other already established forms of technology. The study then proceeds with a review of current applications of VR in product design and development and ongoing research in HE. All of these provide background to the core part of this work — a forecast study on the integration of immersive VR in industrial design education, as imagined by its educators, twenty years into the future.

2 DISPLACING OLD MODELS

In a traditional view, the teacher is the primary source of information and learners the passive recipients. This model has characterised education for the longest time and is still very much alive today. However, and partly due to the unparalleled access to information combined with the educational opportunities technology has brought, this role is now shifting in many classrooms. Students have increasingly more control over what they learn and take further responsibility for it. Teachers have also shifted from central positions onto the backstage, becoming more of learning orchestrators and less of stage performers [9]. Quick and easy access to information, student empowerment over learning, and teacher repositioning constitute three defining changes characterising today's learning environment. All of these find support in a constructive aligned teaching and learning framework, designed in accordance with the intended learning outcomes [5]. A procedure that requires both strategy and skill, supported by a blend of formal and tacit knowledge, to which the capacity to understand the subject combined with the skill to deconstruct it into clear and manageable concepts, is central to its development [27]. More than ever, teaching and learning today relies on the educators' ability to plan and orchestrate a variety of rich and meaningful experiences, with the tools and resources available, that stimulate deeper levels of learning and support the development of new, or the reinforcement of existing, knowledge structures.

The classroom itself, traditionally isolated and with collaboration opportunities limited to physical space, has also changed. Internet-connected networks, display technologies, and portable devices, among others, have led to more flexible learning environments, supported new forms of teaching and expanded the range of learning modalities (e.g., online learning through synchronous or asynchronous forms, blended learning). Nowadays, these find increasing support through the implementation of institutional-wide Learning Management Systems (LMSs; e.g., Blackboard, Moodle). They provide flexible access to a range of tools and resources to both students and teachers and enable a broader spectrum of teaching and learning opportunities to supplement or diversify pedagogic strategies [22]. This integration brings further inclusivity and openness to the learning environment by considering distant or physically unable participants and the varying learning preferences among student groups. However, LMSs are not the only form of technology finding their way into the learning environment, especially during the COVID-19 pandemic [4].

In the last few years, VR has slowly started to be introduced in some educational contexts for various uses. The technology has expanded the traditional classroom beyond spatial constrain and real-world physics, bringing forth a new range of experiences. Although early experimentation as a teaching and learning tool focused primarily on the natural sciences (e.g., astronomy, biology), placing emphasis on visualisation and user interaction with virtual models, it has since grown and expanded onto other fields. In industrial design teaching and learning contexts, as in industry, VR has been experimented with in a variety of situations (e.g., empathy tool, usability testing, co-design), afforded by its ability to enact opportunities for embodied presence, immersive experiences, hands-on activities, or contexts for experiential learning [3],[11],[15-16]. The broad range of possibilities today allows a multitude of different applications and learning outputs across various areas [29-30]. Positive prospects that invite research onto other forms of teaching or modes of learning, further displacing old models of standardised, rote learning in favour of more dynamic, diversified, and flexible approaches.

3 DOWNSTREAM INTEGRATION

Technology influences pedagogy. On one side, it brings additional tools and resources that expand the learning environment beyond the classroom while also providing additional options to educators, who evaluate if these facilitate or not the acquisition of the module learning outcomes. On the other, it does so by directly integrating curriculums. For instance, technological advancement drives the manufacturing industry. The latter influences contemporary industrial design practice, which in turn reflects on its curricular counterpart in HE. This downstream integration of technology ensures in part the relevancy of present-day study programmes and their ability to equip future graduates with the knowledge and skill to match the needs and requirements of the job market. From this perspective, newly matured technology that brings value to the product development process is likely to integrate curriculums not long after becoming established. Consequently, this may either alter, update, or add new content to existing taught modules or entirely lead to new ones. Unavoidable changes that, irrespective of size or impact, command the review of existing curriculums, pedagogical frameworks and current practises, or develop entirely new ones.

Two prime examples of this downstream integration of technology, from industry to curriculum, are the coming of age and widespread adoption of Computer-Aided Design (CAD) and Additive Manufacturing (AM). CAD replaced manual drafting and increased the speed, accuracy, and rigour in creating two-dimensional (2D) technical drawings or three-dimensional (3D) models. Users could now visualise and share a product that was not yet made physical, its sub-assemblies or constituent parts, and modify it all with ease. On the other hand, AM technologies enabled the materialisation of CAD data. A range of technologies that digitally fabricate 3D parts through a layer-by-layer additive process whose maturation meant prototyping and design testing no longer required a high upfront investment in tooling and manufacturing.

The integration of CAD and AM in product development and manufacture dramatically improved productivity by shortening processes, cutting down project completion time, lowering production costs and, among others, facilitating communication between project stakeholders [26]. This reflected both on industrial design practice and its curricular counterpart in HE. The introduction of newly matured technology to the latter represented additional factors to consider when designing or developing module content or project briefings, the activities or tasks that support these, and the pedagogical framework which all integrate [20],[31]. This foresaw that students would gain practice and experience with both and develop the necessary competencies needed for a job market that now required it. Throughout time, this downstream influence of technology has contributed to an increasingly more digitalised design process, mirrored in HE. A tendency instigated by continuous technological advancement [1],[10].

4 VR IN INDUSTRY AND INDUSTRIAL DESIGN EDUCATION

In recent years the manufacturing industry renewed its interest in VR, particularly in product design and development. The technology is being used to virtualise CAD outputs prior to the creation of physical prototypes. Doing so enables a better perception of scale, proportion, and form in simulated contexts [13]. An effort meant to increase product perception, which contributes to a reduction of physical models and waste, time and resources. These lead to faster decision-making processes and a more holistic understanding of the product to be [14],[17]. Although not quite there yet, the next stage in VR applications aims to bring further realism to simulations and the ability to move CAD 3D digital mock-ups (model simulations used for the numerical analyses of product behaviour) directly into production. Doing so involves the creation of richer simulations that expand the experience beyond the visual and auditory faculties. The inclusion of haptic (i.e., the feedback associated with touch) to the mix aims to supplement the simulation with non-visual information about the shape of 3D objects (e.g., feel surface contact geometry, smoothness, slippage, and temperature) [2]. A combination of VR technology with multimodal human-computer interaction (HCI) resulting in interactive virtual prototypes (iVPs; functional models mapped into sensorial terms) [6]. The ability to relay sensory feedback to the user during the manipulation of virtual objects establishes a degree of tangibility between the simulation and the real world, bringing additional realism to the experience.

In industrial design education, VR technology has been experimented with at different stages of the design process. Hamurcu [18] literature review, includs a comprehensive overview of computer technology throughout time reflected as representative tools used in industrial design, and provides a general panorama over VR-related research regarding use or application in industry and education. Their research suggests that studies using VR in industrial design education started appearing in 2016, and look at the technology as a modelling and visualisation tool. However, in professional practice uses and applications diversified (e.g., as tool for evaluating usability and ergonomics, visualisation, presentation or product demonstration, interactive prototyping, a tool for sketching tool, or collaboration). Nowadays, VR is being researched more broadly in industrial design education.

For instance, Häkkilä [15] research presents three case studies portraying how the technology can impact positively on industrial design pedagogy. The first explored VR as a tool to develop empathy through the simulation of visual impairment. They designed a virtual marked route with different checkpoints that each student had to complete four times using an HMD, each time with a different filter applied to it stimulating a different degree of visual impairment. The authors [15] note the positive effect the experience had on students, who developed empathy and a deeper insight into their user group, allowing them to gain a new perspective when considering and thinking about accessibility.

The two other cases involved concept creation, prototyping, and product virtualisation. Focusing solely on the concept stage, the first addressed the domain of smart buildings. It tasked students to develop concepts for an Augmented Reality (AR)/VR Head Mounted Display (HMD) user interface, demonstrated later through low fidelity prototypes. The intention was not to arrive at a final product but to make students think about their product and the user interaction. Introducing new technologies into the scope of the assignment provided a more futuristic or visionary design challenge for students.

The last case study involved virtualisation. Students had to design a next-generation consumer robot. They had to define context, develop a concept, consider form, and explore their design from the human-robot interaction point of view. The process involved a combination of 3D modelling and visualisation using Blender and Google Tilt Brush. The output was 3D printed and design posters made. All digital elements were imported to Unity for a virtual world presentation that could be seen through an HMD. At the same time, their physical counterpart could be interacted with in a live exhibition. Students commented on hedonic aspects related to the experience of using VR as a design tool, and from being able to see their end products from alternative standpoints through virtualisation. Häkkilä [15] concluded their study positively, noting the technology as sufficiently mature to integrate industrial design education.

Roberts [25] share the same view regarding VR maturity for application to industrial design education. Similar to Häkkilä [15], they also present three case studies detailing how VR was applied within an industrial design educational setting. The first case used VR to explore the ideation process followed by transitioning concepts into physical outputs. The intent was to encourage creative and thought-provocative processes, which themselves and other authors [19][21] believe to encourage student motivation and interest. The second case focused on usability testing to better understand the bus user experience. Towards this end, Roberts [25] utilised a VR simulated environment which provided a repeatable platform for testing general use, alternative scenarios, product and service iterations and locating pain points.

The third and last case study involved co-designing with non-designers. It explored the intuitiveness of VR-based modelling tools (Tiltbrush and GravitySketch) for "hands-on digitally mediated making" (p. 1638). The intent was to provide an intuitive way to develop 3D form to scale, bypassing the rigidity and constrain often imposed by industrial design tools such as Rhino or SolidWorks, which require knowledge and execution of 2D shapes before obtaining 3D form. According to Roberts [25] the participants who more fully engaged with the activity were able to produce thoughtful designed sketch models with minimum tuition after a relatively short period. All three study cases conclude on a positive note; however, the authors note a range of challenges and limitations associated with using the technology. These include the lack of student familiarity with the system and equipment, the limitation of sensory attributes caused by the latter, or the lack of industry-standard processes and tutorials.

The studies above represent the first steps given by industrial educators towards inserting VR into their modules to motivate, challenge, or bring more innovative and creative outputs out of their students. In both cases [15][25] there is a clear purpose for the use of the technology and a teaching and learning framework that supports its integration. Even if these applications may require further iterations, they already represent a range of opportunities or possibilities enabled by VR when applied to industrial design contexts. So, and even though the technology is still developing and not widely established, industrial design educators have demonstrated some of its potentials as a design tool alongside flexibility that enables it to be plugged in at different stages of the design process.

5 TANGIBLE INTERACTIONS IN SHARED VIRTUAL SPACES

Virtual learning spaces gained renewed interest during the COVID-19 pandemic when social distancing and quarantine periods forced many to stay indoors. With both staff and students off-campus, a conjoint number of factors limited both communication and amount of learning opportunities (e.g., access to facilities, physical interactions, limited channels of communication). During this period, in countries with a reliable technological infrastructure and internet access, synchronous and asynchronous online platforms become prominent and enabled education to continue uninterrupted. However, exchanging teaching and learning modalities also imposed constraints. Pedagogical frameworks based on problem-based learning (PBL) or experiential learning (EL) had to be re-thought for distance learning via digital means. Design fields with a firm reliance on these (e.g., product or industrial design) were forced to shift emphasis from a "hands-on" approach, rooted on materiality and physically (e.g., material workshops, product fabrication, prototype making), to less tangible digital outputs (e.g., video-conferencing, CAD models and simulations, online collaborative boards). In many ways, this change limited the range and effectiveness of teacher-student or student-student communication commonly taken for granted in on-campus face-to-face contexts (e.g., in-place discussion through sketches or models, context learning, peer-learning, group tutorials and discussions).

Ongoing developments in VR aim to bring tangible interactions into fruition. Although notoriously complex to replicate the human sense of touch, adding tactile capabilities through haptic feedback brings virtual elements a step closer to the real world [2]. An additional feature that would benefit both product design and development, as well as design education contexts. To the latter, it would mean that distance-learning modalities (or even on-campus activities) could become an enriched, interactive and immersive, multimodal experience. A future vision for industrial design education that, although reasonably conceptual, does not fall outside the realm of possibility.

Haptic feedback VR gloves and bodysuits have been explored since the late 1980s early 1990s. Contemporary VR gloves are capable of providing varying degrees of feedback and enable more natural or intuitive interactions. Even though they benefit the overall VR experience, they also have their limitations. Generally, factors such as cost, weight, size, or accuracy are commonly highlighted, reflecting a need for further iterations and development [12],[32]. Regarding bodysuits, the TeslaSuit is amongst the latest; a smart textile two-piece full-body suit that provides full-body haptic feedback while also capturing both motion and biometrics. The suit intends to provide users with sensation and a sense of touch in simulated realities (AR and VR), consequently improving the learning experience by increasing immersion [28],[23-24] fostering 360-degree awareness, and engaging muscle memory. These developments aim to realise richer multimodal experiences in simulated environments, and provide sufficient grounds for speculation about future use-scenarios in industrial design education.

6 VR AND ONLINE EDUCATION

Many of the VR products available today (e.g., VR bodysuits or gloves, omnidirectional treadmills, HMDs) are reminiscent of Ernest Cline's [7] science-fiction action-adventure novel "Ready Player One", adapted to film in 2018. The story takes place on planet Earth in the year 2045. Its current state is characterised by an ongoing energy crisis, catastrophic climate change, poverty, disease and war. This real-world context is contrasted with a globally networked virtual reality called the "OASIS", a massively multiplayer online game (MMOG), which most humanity uses daily for various ends. Basic access to the platform requires a VR Head Mounted Display (HMD) and haptic gloves; however, additional hardware can be purchased to increase immersion and the simulation's realism (e.g., suspension rigs, bodysuits). On entry, users (hereafter referred to as players) are embodied in an avatar, a digital 3D visual representation of themselves [8]. Inside, players can explore, compete in, and launch multiple VR experiences according to their interests or motivations. Most of the story happens in this immersive virtual world, which narrates the protagonist, Wade Watts, quest for OASIS's creator James Halliday's hidden Easter egg.

Absent from the film adaptation are some of the book's author passages that portray his views on online learning in immersive 3D virtual environments. Chapter two of the book introduces Wade's virtual learning environment inside the OASIS Public School #1873 (OPA#1873). Accessible through a school-issued OASIS console, the school is one among hundreds spread out across Ludus, a planet dedicated solely to learning that automatically disables features unrelated learning upon entry. Once Wade logs in to OPA#1873, the author describes a range of interactions that provide insight into the functioning of the virtual environment and HCI (e.g., "I began to walk my avatar down the hall, using a series of subtle hand motions to control its movements and actions" (p. 29)). Also portrayed are some interactions between Wade's avatar and the mediated environment or other participants and some of the system features available to him (e.g., voice commands, ability to mute others, avatar customisation). A few passages later, the author provides the backstory leading to Wade's choice to attend school online rather than in the real world. The passage describes his struggle to fit due to his social awkwardness and lack of confidence resulting from his poor personal appearance (physical and clothing) and recurrent bullying. He resumes it all to "a daily gauntlet of ridicule, abuse, and isolation" (p. 31).

The brief yet well-grounded narrative provides a utopian view of what online education in 3D immersive VR environments could look and feel like in the future. It also offers possible causes that may bring it into realisation, beyond personal reasons or afflictions (e.g., densely populated urban areas, overcrowded public school systems, extremely high tuition fees for private schools). Tangible elements that in many ways reflect some of the present-day ongoing changes in education. Technological advancement, the growing technological footprint in the learning environment, and an increasing move towards virtual learning places may all very well lead to similar scenarios. Persistent changes that create doubt about the future of design education, especially on the how or in which ways, technology and the growing digitalisation of educational systems will impact areas that are notoriously rooted in tangible elements or contexts.

7 METHODOLOGY

With the aforementioned in mind, the present study set out a clear research path; to dwell onto plausible futures of industrial design education, as imagined by present-day educators, twenty years from now — a future where VR and the design studio are integrated. The aim is to forecast how the maturation of the technology and possible subsequent widespread adoption could affect design activity and design studio dynamics. Portray what educators imagine to be the key changes in how design is taught or learnt or how design activity may grow into something substantially different from today. These contribute to the study end goal, which pretends to present a plausible depiction of what the future may bring, induced by the increasing digital footprint in industrial design education. To fulfil this goal, participants contributing to this study had to be HE educators currently active in industrial design or a closely related field (e.g., industrial or product design and mechanical engineering are proximate) and have knowledge or practical experience with VR.

The study relied on primary data collected through a questionnaire made available online between April and May 2021. A total of 119 pre-selected individuals were invited to answer. The selection was based on their field of specialisation and research outputs relating to uses or applications of VR technology. They were identified through their published work, either authored or co-authored and made available online via Researchgate.net or ScienceDirect.com. Using the contact details present in their publications, each individual was sent an email introducing the study, alongside an internet address leading to the online questionnaire. An identical email was sent out through a contact network of industrial or product design educators known to have a degree of experience with the technology. This combined procedure resulted in twenty-five complete answers (n=25) from participants across five continents.

The questionnaire was composed of eighteen questions, divided among three parts: familiarisation with VR, plausible futures, and demographics. The first part filters and categorises participants through a combination of close and open-ended questions. The second is purely speculative and utilises sentence completion questions to enquire participants about possible utopian or dystopian future scenarios involving VR technology and the design studio. As a whole, the questionnaire gathered both quantitative and qualitative data. The first type is analysed using descriptive statistics, while the latter is analysed and interpreted through inductive coding, using the MAXQDA software.

8 RESULTS

8.1 Demographics

Participants are HE educators, academic researchers, or both. Regarding their specialisation, options were not mutually exclusive and the most often is industrial or product design (64%), followed by CAD/CAE/CAM (36%), product or mechanical engineering (28%), and user-interaction or user-experience design (24%). 68% lead a design studio module or co-teach in it. The largest group is based in Europe (64%), followed by Asia (20%), Oceania (8%) and, sharing an equal 4%, North and South America. Most have been active in HE somewhere between 5 to 9 years (32%), a slightly smaller group with "20 or more" (24%), and 20% between 10 to 14. Concerning professional practice, outside of HE, 36% indicated 1 to 4 years, followed by the 10 to 14 interval with 28%, and the 5 to 9 with 16%. Gender wise, there is an inclination towards male respondents (60%) and, in terms of age, the most prominent groups are the 25 to 34 and the 35 to 44, with 40% and 32%, respectively.

8.2 Familiarisation with VR

No participant has a complete lack of knowledge about the technology. 72% are familiar with the concept of VR and have practical experience. The origin of their experience is divided into three main groups. The largest is a combination of both research and education (50%), followed by just research (27.78%) or just education (11.11%). The topics of research and uses in teaching and learning vary and are summarised below in Table 1 and Table 2. In connection to their experience with VR equipment, the most commonly referred to are HMDs (94.44%) and hand-trackers (66.67%). Options provided were not mutually exclusive and these initial two were followed by "CAVE Automatic Virtual Environment" (50%), haptic gloves (33.33%), facial tracker (22.22%), smell sensory mask (11.11%) and lastly, with 5.56% each, omnidirectional treadmills, haptic vest or bodysuits, and rudders. In the option "Others, please specify", three participants added the following: "Semi-immersive system using Acer H6510BD 3D Video Projector and NVIDIA (model 3DVision2) shutter glasses", "Haptic devices like Haption Virtuous desktop 6D and high variety of HMDs, CAVEs, Power-walls, etc.", and "Hyve3d (hybrid virtual environment)."

Material perception
Cinematography and immersive audio
Engineering applications (e.g., design review, simulation, visualisation)
Conceptual design and plant configuration
Design expression and interaction
Education
Integration into the design process
Content creation

Table 1: Summary of participants' research focus.

Contextual learning through simulation
Design methods (e.g., empathy development, user-journey)
Gateway for expression, imagination, and abstract creation
Virtualisation of projects or assignment outputs
Remote collaboration

Table 2: Summary of participants' use of VR in teaching and learning applications.

8.3 Plausible Futures

The central part of this study is built on three sentence completion questions. Before revealing any, participants were introduced to the following scenario description:

"Twenty years from today, the design studio is a hybrid taught module, partly taught on-campus and partly taught online in immersive 3D virtual spaces. The on-campus design studio also has large areas dedicated to VR; during class, students can be given activities or tasks that require its use. VR technology has developed. Head-Mounted Displays (HMDs) look like normal reading glasses. Haptic gloves are no different from normal gloves. Movement sensors and surrounding

audio are integrated into the design studio space. Everything is wireless. Other technologies such as Artificial Intelligence (Ai) and Big Data applications have also developed."

Once read, participants were asked to keep it present while addressing the questions that followed. Each intended to situate participants in a specific position in relation to context. They were presented as follow:

1. *In the scenario above, I imagine myself (or my students) using the VR area inside the design studio to …*
2. *Using VR in the design studio for that purpose (your answer above) led to a consequent change in behaviour(s). Myself (or my students) …*
3. *All of this had implication(s) beyond the design studio. Stepping back, I could perceive a larger change in context. The following became apparent to me, …*

The first sentence completion question places the participant inside the design studio and prompts for an action. Its focus is on the practical use or application of VR technology (e.g., how participants imagine using the technology for teaching and learning related activities). Once specified, the second question shifts perspective and redirects them to focus on behaviour; for instance, how utilising VR to accomplish that initial action could alter design studio dynamics, the way students approach future projects, conduct research, or others. Participants were asked to write down behaviours, positive or negative, that could be observable, describable, or measurable in some way. The first two questions also gave participants the flexibility to either write from their point of view, project themselves onto a hypothetical student and answer from his or her vantage point, or do both. The last sentence removes the participant from the design studio and prompts them to write down changes they could foresee happening in a larger context. Essentially, imagine potential implications on a macro scale (e.g., altering of teaching and learning dynamics, curriculums, educational ecosystem).

Each set of answers, multiplied by the number of participants, defined the spectrum of possibility across three distinct levels: uses and applications, consequential behaviours, and implications. The dataset from each level is analysed and interpreted through inductive coding. Data segments in each response were tagged with an in-vivo or descriptive code. These are organised and grouped into different categories, nested under larger concepts.

8.3.1 Level one: uses and applications

The first sentence completion question required participants to indicate potential uses or application of VR technology in the design studio twenty years in the future. Participants comments were analysed and coded in MAXQDA. The coding procedure resulted is a total of 52 in vivo codes, distributed among six categories. They are as follow:

1. **Boundless creation**: highlights the playful side and creative freedom that the technology affords — the ability to create, unbound from the constraint imposed by real-world physics. Participants mention the richness of opportunities for free experimentation and representation of ideas through form, elements (e.g., water, fire), texture, or sounds and learning and engagement with design fundamentals (e.g., modularity, symmetry, colour contrasts, textures).
2. **Context simulation**: refers to the flexibility to simulate a wide variety of contexts, real or imaginary, and easily alternate between them. Students can present their initial ideas or concepts in context, enabling them to assess their appropriateness, meaningfulness, impact, or similar. Assignments or project reviews also occur with products in context, allowing a better assessment over the solution's suitability. Creating simulations also opens the design studio to more project possibilities; seeming impossible contexts become

tangible (e.g., design for a human settlement on Mars). Immersive simulations also bring an additional depth and context to case study analysis.

3. **Collaborative or participatory design**: the most often described use of the technology in the design studio involves remote and co-located interactions between different people. Educators, students, design practitioners, industry representatives or field experts all meet in immersive virtual spaces to share research, conduct design work, project reviews or discussion, among others. Participants seem to believe that a substantial part of the design process will occur more frequently in immersive VR. This will remove a series of real-world impediments (e.g., travel distance, associated costs and time, availability) and bring project stakeholders closer. The growth of meaningful and tangible interactions in virtual space will contribute to better informed, more suitable, or overall more robust end products and the establishment of stronger synergies with both educational and industry partners.
4. **Virtual prototyping**: virtual models become tangible, closer to reality, leading to a substantial decline of their physical counterpart. Parts can be modelled, assembled and disassembled, handled or interacted directly in virtual space. Ai plays a role in assisting creation, iteration, and refinement through analysis, simulation, and evaluation of the designed product against different databases (e.g., human factors, consumer preferences), in real-time and present multiple viable iterations based on set parameters.
5. **User-research**: there will be multiple ways to connect and interact with users. VR provides students with additional opportunities to develop empathy by immersing themselves in the user context or the user himself through the embodiment of a pre-configured avatar with specific characteristics (e.g., physical ability, blurred vision, hard hearing). This repositioning will allow students to experience the appropriateness of the products, systems, or services they design from the user's perspective and promote genuine empathy for a hugely diverse range of users, leading to more inclusive designs.
   Participants also refer to the ability to transport students, during class, to contexts they would not have access to in real life and become immersed and exposed to a plethora of multimodal feedback (e.g., visual, auditory, olfactory, tactile). For instance, travelling to another country and immerse themselves in its local culture, tradition, food (e.g., smell, composition, taste, texture) or others.
   Lastly, and considering that the technology allows access to multiple virtual worlds, populated with a diverse variety of users, students can use the medium to conduct interviews, establish focus groups, run questionnaires, or do remote user-testing of virtual products.
6. **Training:** minimise health and safety hazards and enable skill training to occur at any time and from anywhere. Participants refer immersive virtual visits to factories where students can better visualise and understand manufacturing processes, attend workshops for training with specific machinery or processes/procedures, and join virtual labs for an assortment of activities (e.g., product assembling/disassembling, problem-solving).

The areas with the most amount of code tags are the "collaborative or participatory design" with 15, followed by both "context simulation" and "virtual prototyping", with 9 codes each. All categories and their corresponding weights are represented below in Figure 1.

Figure 1: Number of codes defining each of the six uses and applications categories.

The section that follows explores and characterises the main concepts in the second dataset. The narrative is rendered with a combination of participants quotes or verbatim and subsequent interpretation. Results are summarised at the end of the section in Figure 2.

8.3.2 Level two: consequential behaviours

A "dynamic adaption of both users and content through changes made throughout the process." Students become more engaged with the act of creation. They demonstrate an increased awareness for a multitude of factors contributing to or influencing their designs, made possible by a broader range of experiences at their immediate disposal. The access to multiple degrees of information, in the form of immersive experiences or people, substantially enriches the learning process and improves the appropriateness of the work produced. They are "able to interact with different cultures", develop a "better awareness of different global and social perspectives", "get the information they need and test their concepts and prototypes faster and more effectively", "think cognitively and solve multi-parameter problems."

The digital reproduction of product assemblies in VR allows closer inspection of "physical phenomenon such as dynamic/kinematic interactions among components" (e.g., digital twin). Product system simulations become more accessible to examination and study. Students can interact with its different layers, decompose mechanisms, conduct an array of simulations (e.g., motion, stress) at different stages of their virtual teardown and better understand the interaction or relation between parts. The experience supports a more holistic understanding of product systems. It allows to imagine and recall interactions or inter-dependent movements more vividly and more accurately depict "where something is wrong or which parts may need particular attention (e.g., interference)."

VR areas in the design studio facilitate collaboration or co-creation opportunities. "Students become more collaborative", and the "collaboration among students would happen seamlessly and simultaneously." Different groups of students can "work on one aspect of the product, and it would be possible to design it in a fraction of the time." The whole design process unfolds faster. There is no need to wait "for students to design for the next class; the modifications can be done immediately," which "might change the length of the classes or the challenges." Potentially, there could be "more [briefings] since the duration of the process becomes shorter." Tutors can join students in VR to "guide the process", provide "feedback in real-time", or "evaluate students work live", and have a "better understanding of the working principles of the proposed ideas." Reviewing student work at later stages is also done differently. For one participant, "instead of looking at the PPT slides from students," he or she may choose to "review the scenarios and 3D models directly in the created immersive virtual environment."

Responsive virtual spaces and the normalisation of Ai as a learning aid will play an essential role in the success of VR as a tool for design and learning. An array of "basic functions will be done by an intelligent tutoring system covered as a virtual agent/avatar." Students are remanded to VR learning spaces where Ai-enabled virtual tutors guide and instruct them through dynamically interactive simulations. They gain an increased level of autonomy, the ability to tailor their learning and its depth, as well as build up confidence in a broader range of subjects or skills. Design studio tutors can easily monitor the entire class learning curve based on individual levels of engagement with the system and the tracking of their digital footprint. VR becomes a gateway to a treasure trove of assisted or autonomous learning experiences that require little or no supervision from the tutor, freeing up time that is now redirected towards other parts of student projects.

Most participants are keen to envision a more digital-based pedagogy in the design studio; however, they also wonder about the losses or imbalances that it may lead to and how this will affect student development. Their concerns concentrate on two particulars issues — the distancing between teachers and students and the latter's relationship with physical materiality. The first assumes a loss in the amount of physical human interaction and engagement between those involved in the design studio or, like a participant eloquently puts it — "I see a loss of engagement with the students and it is more focused on the "tangible" outcomes of the interaction rather than emphasis on the interaction itself." The ramifications of this vary. Among others, it may lead to frailer bonds between tutors and students, impair the maturation of their design thinking (e.g., understand users, challenge assumptions, redefine problems), conceptual thinking or design discourse (e.g., the intersection of the practical and the abstract). These exert influence over student growth, both as an individual and future designer, their comprehension of design activity, and level of creativity demonstrated through their work.

Students lose contact with materials. The general feeling is that a substantial part of the practical knowledge involving material transformation or fabrication weakens, consequently affecting student appreciation for the handcrafted or handmade. These are portrayed in comments such as "less access to physical materials and loss of appreciation for handcraft ", "less physical prototypes", and "designing with VR or Ai may encourage concept generation and prototyping but reduce the hand-making skills." The growing digitalisation of design studio activities means that "students may lose the opportunity to "feel" the physical materials or build up a good, natural sense of directly manipulating them."

One lesser mentioned but equally relevant downside is its possible impact on the user health and wellbeing. Heavy use or unlimited access to VR environments are prone to undesirable situations or outcomes involving "addiction to the virtual world", physical exhaustion or cognitive fatigue that, on the long-term, can lead to serious consequences (e.g., "eye diseases, mental deterioration") or other yet unknown consequences.

Overall, teaching and learning activities become a play between virtual and physical experiences, according to the needs of each project. Students are more engaged with design activity, demonstrate a deeper level of knowledge over a more comprehensive set of variables influencing their projects, and are more prone to collaborative or cooperative work. These changes, promoted by different uses and applications, are perceived to contribute to developing higher-order thinking skills and better, more informed design work, accomplished in shorter periods. However, not all is deemed favourable. Integrating the technology requires a carefully crafted pedagogy that can balance digital and physical processes and preserve, protect, and build around industrial design core elements. Ensure that although a growing number of processes may tilt towards digitalisation, the path never strays from interacting with people, exploring what connects them to products (e.g., semantics, emotion, playfulness, culture), and develop an appreciation and sensitivity towards the handmade and the materiality of things.

Figure 2: Main consequential behaviours derived from uses and applications.

All proposed uses or applications and derived consequential behaviours have implications on a larger scale, beyond the design studio and its intervenients. The section that follows builds a ramified narrative of these based on participants foresight. The account is written from a future perspective and utilises and interprets their quotes for contextualisation and scenario building. Results are summarised at the end of the section in Figure 3.

8.3.3 Level three: implications

The "integration of VR in education, industry and larger society is probably inevitable." The design process will expand to "include techniques of working with VR and Ai as the standard tools." The establishment of these in professional practice leads back to industrial design curriculums. A complementary set of study subjects co-integrates the curriculum to support its insertion and facilitate proficiency among industrial design students. Programming or algorithmic logic become new creative skills that students need to develop and use during the design process. Design related activities grow more digitalised. There is more emphasis on CAD models and VR outputs; less on material or fabrication workshops and physical models. "Diminishing physical modelling skills impact form giving." Form becomes the new realm of algorithms; mathematic equations eclipse human sensitivity and the meaningfulness of form. Industrial design outputs lean towards the emotional sterile and rational but, at the same time, become more informed and robust.

"Barriers of geography, scale, budget, age, background, disability" disappear. "Collaboration becomes limitless and offers the possibility for the sharing of knowledge, solving of problems across geopolitical boundaries." All of it will create new opportunities for design, education, and research. Context situated multi-cultural teaching and learning activities with local hosts, in-depth case study analysis and reviews with field experts, worldwide participatory design workshops, more robust research studies with a wider variety of participants, among others, will all contribute to the exponential growth of good design. A "larger network to access the information when we want/need" will bring "more sources, more ideas, more challenges" and "more diversity" into the learning environment. All of it will "boost cooperation and understanding across peoples and the sharing of ideas and new thinking — where ideas and designs can be tested and ratified in a supportive and collegiate manner."

"The volume of information and stimulus [in a VR predominant teaching and learning modality] would be very high", so "artificial intelligence would replace many of today's processes during design in VR." Tutors would have to hop between multiple VR learning environments, constantly shifting mindset throughout the duration of the class according to each project they review. This subjects them to a plethora of multimodal feedback and a heavy cognitive workload. To manage such a scenario, a more significant number of tutors would need to be allocated to the design studio and smaller groups of students assigned to each. Alternatively or additionally, to prevent the weight down on tutors, more straightforward or more basic tasks can be delegated or supported by Ai. Potentially, these could lead to the "improvement of the teaching quality, because human teachers can concentrate on higher-order cognitive skills and issues of the students."

"Education will no longer be teacher-based." The inclusion of Ai tutoring changes the studio "learning dynamics" and "students attitude" who now "learn on own pace" and, depending on the quality of the simulation, may even "perceive the virtual tutoring agents as real humans." "The pace at which the student can learn can be faster" due to it; however, the potential benefits of creating and integrating these automated systems are not risk-free. Not only can students "take this more as a game rather than an actual training/educational/design tool", especially if "not well integrated with other design tools (e.g., CAD)", but may also become a contributing factor to other serious conditions such as "psychological disorders in users who cannot make out the difference between real and virtual world/agents."

"The education system pedagogical approaches should adapt these technologies to integrate into design process rather than a representation tool." All of it would require "a higher level of coordination and organisation" and an increased focus "on how to teach in a digital environment like VR." Changing how teaching and learning occurs requires commitment from all stakeholders, particularly from HE institutions. The latter is expected to provide both the technical and infrastructural support that will enable educators "to create new pedagogical activities" and support student learning in VR environments. The teaching and learning framework, particularly for the first-year cohorts, demands forethought. "The activities involved in a course on design fundamentals require direct sensory involvement with materials and manual skills, the use of VR demand careful consideration." Emphasising digital or virtual processes this early in the programme, rather than at a later stage, is an anticipated detriment to student maturement and appreciation for core elements of a HE degree in industrial design.

The implications foreseen by participants show streams of thought, concern, or optimism. The recognition of value in utilising VR or Ai-based tools in the design process leads to its broader establishment. Curriculums adapt to include their application, and other taught subjects are incorporated to support it. Using VR gateways for design education or research enables both tutors and students to immerse themselves in worldwide contexts and experiences, collaborate with others and work directly in virtual space. How teaching occurs today may not be compatible with these changes; the overabundance of information will make it overwhelming. Ai tutoring systems come into play to offset the surplus but, overuse or over-dependence on these may lead to some anticipated consequences and others still unforeseen. The use of this type of tool in first-year cohorts is frowned upon. The introduction to design fundamentals should, among others, induce in students an appreciation for handmade and a sensibility towards materials — something to be nurtured throughout the course. Digital technology should build on top of it and open new venues for communication rather than deter or overtake the former. Twenty years from today, a balance between physical and virtual, irrespective of the growing digitalisation, will still be deemed central to industrial design.

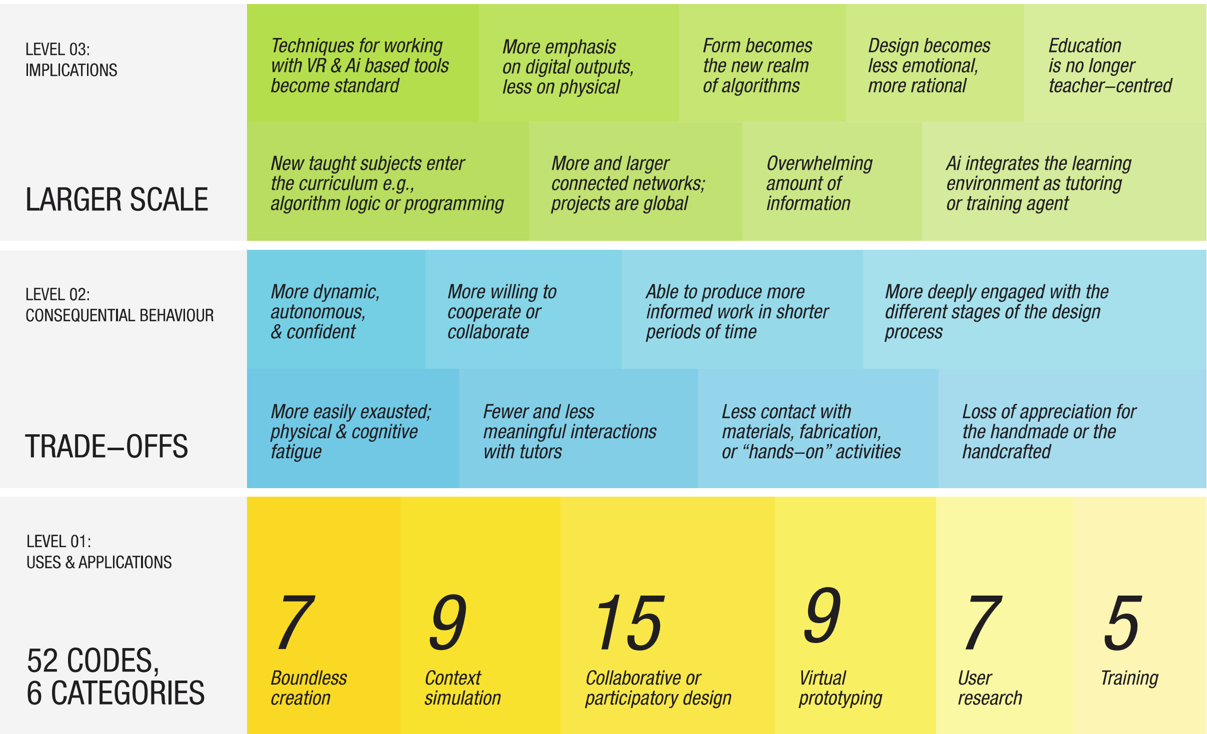

Figure 3: Diagram showing all key points pertaining to each level, with level one at the foundation.

9 DISCUSSION AND CONCLUSIONS

"The application of VR is highly dependent on the development of technology." The multitude of variables and their probabilities for success make the future extremely hard to foresee, even if only twenty years ahead. No one can be entirely sure about what technology will look like, which one will succeed, or even if the successful ones will have applicability as design tools or be suitable as a platform for teaching and learning design. However, the one thing that seems clear is that technology advancement is unlikely to slow down and "virtual and physical will all be design skills we need to start fully taking into account for design education."

Amid a Fourth Industrial Revolution (or Industry 4.0), this study sought to speculate how VR technology may influence industrial design education in HE twenty years into the future. The goal was to imagine and depict what may lay ahead and how educators see it affecting industrial design day-to-day pedagogy, the learning environment or the educational system. This required study participants to have a background in the area (or a proximate), and experience with the technology. Their familiarity and experience with the technology makes them the ablest to discern and evaluate future potential based on its current form or impeding development.

There is a consensus that VR is a valuable tool for design. Its portrayal in industrial design learning contexts inclines towards utopia. Integrating the technology, directly or indirectly, is perceived as contributing to more dynamic and collaborative behaviour, a deeper level of engagement in the design process, better awareness for different streams of information, and an overall more confident, autonomous, and independent design student that can accomplish more in shorter periods. From more collaborative opportunities to more robust and inclusive research, the design studio is enriched with new experiences and access to a more considerable amount of information in various forms.

Some participants, however, are wary and do not share the optimism. Their perspective over the matter is more balanced, weighing potential benefits against possible drawbacks. The most often referred negatively is the perception that the technology will weaken, or at least significantly reduce, students contact with materials, handmade activities and their sensibility towards both medium and process. The growing digitalisation is also somewhat perceived as distancing those involved in the design studio, where the focus of the interaction between participants shifts from the interaction itself to more tangible and practical outputs. Only one participant mentioned this loss, but the comment was so eloquently put that one cannot help but wonder about the consequential effects that a higher dependence or reliance on technology has in design discourse, dialogue, argumentation, and critical thinking.

The teaching and learning experience for both teachers and students is perceived to change substantially. The heavy amount of information becomes incredibly more challenging for teachers to manage on their own. Their role is likely to change and focus more higher-order tasks while Ai tutoring becomes an everyday reality. The latter will be able to support tasks such as training, product iteration or optimisation, among others. Implementing this type of system will have its positives and negatives, some easy to imagine (e.g., cognitive fatigue, virtual addition, isolation) while others are likely to become known only in time.

To answer the question that led this study, there are multiple ways in which VR technology can influence industrial design practice and education. Although its use and applications are more easily coupled with visualisation and CAD, there is a range of other categories that can benefit a great deal. One of these is research; the ability to immerse oneself in another's culture and experience it first-hand will create a more memorable or long-lasting impression, even if through simulated environments. Learning more about people, their habits, culture, traditions, or becoming their users through virtual embodiment is all imagined to become possible. A vision towards a future that would create far more emphatic and knowledgeable industrial designers whose work would reflect this newly developed sensitivity and awareness. Design activity would become far more inclusive, better understood from the user perspective and in line with real rather than hypothesised needs based on distant, misinterpreted contexts. All of it could bring design work a step closer to good, universal design.

10 LIMITATIONS AND FUTURE WORK

This small-scale research study portrays an interpretation of what a possible future of industrial design education may look like in twenty years, based on the input of present-day educators with experience in the area. The study's small number of participants and speculative nature make any conclusion inevitably limited in its scope and generalisability. Conclusions seek solely to portray what design educators believe the future of industrial design education looks like today and, in the process, attempt to open new (or reinforce existing) paths for future research, inquiry, or design work. Some of these may include research into the development and use of VR extensions integrated into Learning Management Systems (LMSs), materiality in VR environments, educational paradigm changes, or VR-based pedagogy and teacher-student dynamics.

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