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Physical meets digital: Advancing industrial design higher education through the incorporation of projection-mapping in undergraduate teaching and learning

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Abstract

As emerging digital technologies become increasingly integrated into our everyday lives, it is important to evaluate how they can be used both as beneficial tools in the design process and how they can be effectively integrated into higher education pedagogy to enhance teaching and learning processes. As we enter the fast-changing Industry 4.0, students must be suitably and sufficiently equipped with a wide range of skills that Industry 4.0 requires. This includes the “hard skills” of practically using emerging digital technologies, as well as the “soft skills” required to effectively apply these technologies in sustainable and ethical ways. Consideration for how technology can be integrated into undergraduate teaching and learning advances programme offerings by equipping graduates with the skills necessary to participate in their evolving industry.

Projection mapping, also known as spatial augmented reality, is the process of superimposing digital images or videos onto 3D surfaces through digital projection. These surfaces can range from large objects such as building facades, to small-scale everyday products. The advancements of projection mapping present exciting possibilities in design processes and outcomes, such as showcasing multiple product surface finishes, colours and textures on a single 3D model, generating dynamic and changing spaces or installations, or creating engaging and immersive product advertising, to name a few.

Aligned to the subtheme of “Doing: Exploring new pathways in design education”, this paper reports on a three-year qualitative action research project, comprising five undergraduate Industrial Design projects, exploring the potential means of enhancing teaching practices by effectively and efficiently incorporating projection mapping into student projects to achieve increased student engagement and learning. This paper presents an overview of the project’s context and methodology together with a selection of project outcomes and key findings through a discussion of student and lecturer reflections regarding the relevance and efficacy of incorporating projection mapping into undergraduate teaching and learning.

Keywords: Action research, digital technology, industrial design, industry 4.0, projection mapping.

Introduction

Klaus Schwab (2016:8) defines the Fourth Industrial Revolution (4IR) as the fusion of technologies that blurs the lines between the physical, digital, and biological domains. Across the creative industries, the 4IR is expanding the possibilities for creativity, collaboration, experimentation, and innovation. Emerging technologies are significantly impacting the field of Industrial Design, transforming the way products are conceived, developed, and manufactured (Ferrari 2017). The means through which designers can visualise, prototype, and communicate or test their designs are becoming faster and more dynamic, enabling designers to iterate and refine their concepts more efficiently. The field of industrial design has also shifted from being product-focused to being more service and service orientated (Ferrari 2017).

It is argued that Higher education curricula must continuously adapt to incorporate emerging and relevant technologies to best equip students with the skills and knowledge needed to thrive in a digitally driven industry (Penprase 2018, p. 217; Adelabu & Campbell 2020). However, incorporating these technologies into a curriculum, not only provides the necessary tools and skills for participation in industry but can also engage students more interactively and experientially (D'Angelo 2018). It is, therefore, also important for Industrial Design higher education to explore how technology can be used to enhance the way students learn, explore, and apply design principles.

This paper presents findings from a three-year action research project which explored means of incorporating projection mapping into industrial design undergraduate projects with the aim of achieving increased student engagement and learning. This paper provides an overview of the research context and methodology, gives a description of the student briefs, highlights a selection of project outcomes, and discusses significant findings by examining the reflections of students and lecturers.

Context

This research took place in the Department of Industrial Design at the University of Johannesburg. As the oldest and largest of four tertiary institutions offering Industrial Design in South Africa, we acknowledge that the department is well resourced in the technology mentioned below, and this may not be the case in all tertiary institutions in South Africa and Africa.

Because the field of Industrial Design is so closely aligned with technological shifts (Ferrari 2017), the curriculum taught within the department (and most higher education institutions) already integrates many digitally driven tools. Examples of technologies that are already integrated into the department include paid-for and open-source digital design and prototyping tools such as 2D and 3D CAD software. These technologies allow students to create, visualise, and iterate designs in a virtual environment. Digital fabrication and rapid prototyping technologies like 3D printing, laser cutting, and CNC machining technologies are also commonly used within larger industrial design departments. These tools enable students to create physical prototypes of their designs quickly and cost-effectively, allowing them to evaluate the usability and functionality of their products.

As 4IR continues to blend the physical and digital realms, it is important for higher education institutions to evaluate the benefits these advances offer to the practice and explore effective ways of integrating them into teaching and learning. Virtual reality (VR) and augmented reality (AR) are examples of newer technologies that allow designers to merge the digital and physical realms. Virtual reality (VR) is a fully immersive technology that allows users to experience and interact with computer-generated virtual 3D environments using specialised hardware, such as a VR headset or goggles (Jerald

2015). Augmented reality (AR) describes a "real-time direct or indirect view of a physical, real-world environment that has been enhanced/augmented by adding virtual computer-generated information to it" (Carmigniani & Furht 2011, p. 3). While virtual reality (VR) completely immerses users in a virtual/digital world through a headset, AR blends the physical and virtual worlds together, typically using a device like a smartphone or AR glasses and superimposes virtual objects and cues upon the real world in real time (Carmigniani & Furht 2011, p. 3). While VR and AR both offer significant opportunities for application in Industrial Design, they require powerful (and expensive) equipment, such as headsets, AR glasses, smartphones, etc., making them inaccessible in most contexts and preventing them from being effectively and equitably integrated into teaching and learning processes. Comparatively, projection mapping is a tool that can achieve similar practical and learning outcomes at a much lower cost as it makes use of technologies that are readily available to consumers (Rowe 2014, p. 156).

Projection mapping, also known as spatial augmented reality (SAR), is an adaptable and dynamic technology that brings together the realms of art, technology, and design. Projection mapping is a simpler version of AR, which uses projectors to map images and animations onto real-world objects or surfaces (Rowe 2014, p. 155). By accurately aligning digital images, videos, or animations onto a surface or structure, projection mapping can transform static objects into dynamic displays, offering unique and immersive approaches to design visualisation (Katkeviča & Strode 2022, p. 1004-1005). In the context of the design process, projection mapping serves as a powerful tool for communicating design ideas to stakeholders, clients, and end-users, enabling clearer and more engaging presentations as students bring their concepts to life in dynamic and interactive ways. With its ability to blend the digital and physical worlds seamlessly, projection mapping offers endless possibilities for creativity and immersive experiences (Rowe 2014, p. 156). Projection mapping itself dates to the late 1960s when it was mostly used for special film effects and film studio amusement parks (Katkeviča & Strode 2022, p. 1004). Since then, projection mapping techniques have gained popularity and application in several industries, such as entertainment, advertising, marketing, interior design, education, exhibitions, events and brand experiences to name a few (Katkeviča & Strode 2022, p. 1004-1005).

As projectors are already an available tool within the department, the technology is accessible and well understood, making the uptake of projection mapping as a new technology faster and more effective than VR. Industrial Design graduates work in a wide variety of industries and given the vast number of applications of the projection mapping medium, make it a relevant skill to incorporate into an industrial design curriculum.

Theoretical framework and methodology

According to Sanford, Hopper, and Starr (2015, p. 28), "learning can only take place when the learner is engaging in an active process of building and creating knowledge through participation and interaction". Framed by Dewey's (1986) pragmatic philosophy on learning through experience and reflection, this research draws on David A. Kolb's Experiential Learning Theory (1984) and Kurt Lewin's Action Research Model (1946), specifically, their emphasis on learning through experience, reflection, and action. With the goal of reflective learning, action research is an approach to educational research that educational practitioners and professionals commonly use to examine, and ultimately improve, their pedagogy and practice (REF). This study explores the potential for enhancing teaching practice by incorporating projection mapping into the Industrial Design curriculum through project-based inquiry (Lewin 1946). Instructors aimed to create engaging learning experiences by experimenting with projection mapping within the existing departmental project briefs, all with the aim of enhancing student engagement and improving learning outcomes (Clark, Porath, Thiele & Jobe 2020; Kolb 1984).

The research followed a qualitative action research approach and involved five undergraduate Industrial Design projects (Action Research Cycles) conducted between 2021 and 2023. These projects took place in varying practical modules and spanned across different academic levels, ranging from first to third-year students (Figure 1). For each of the five projects/cycles, the steps of Plan, Act, Observe, and Reflect were followed (Altrichter et al. 2002, p. 130). Planning encompassed the development of the project brief and the definition of project requirements and assessment criteria. The "Acting" phase involved executing the project, while the "Observation" phase entailed lecturer observations and the assessment of project outcomes. As teaching and learning are interrelated in the effectiveness of education, lecturers and learners must be involved in the reflection (Schratz 1992, p. 83). At the end of each project, students were asked to reflect on the process and outcomes by completing an online questionnaire (Schratz 1992, p. 87). Finally, the "Reflection" phase involved the analysis of student and lecturer reflections and sharing key findings to inform the following cycle.

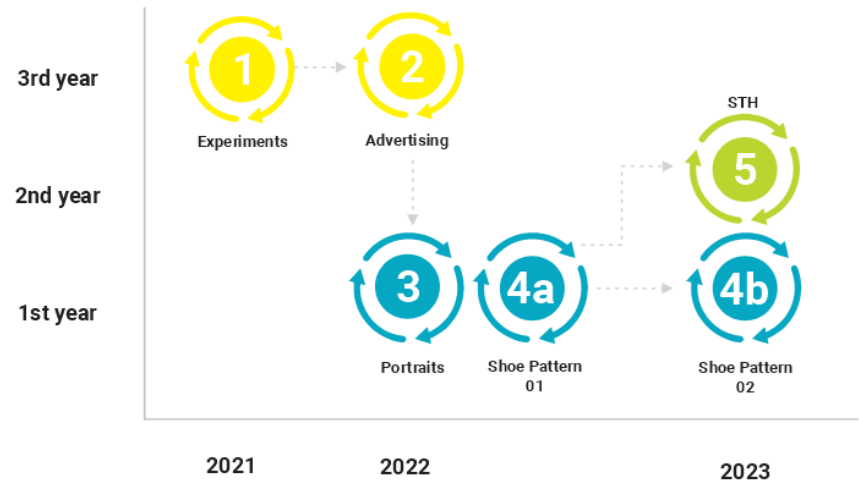

Figure 1: Action Research Cycles 2021-2023

To give context to the research findings, we offer an overview of each of the five project cycles, including details about the project brief and its requirements. Additionally, for each project, we showcase various project outcomes to showcase the efficacy of each project.

Cycle 1: Initial experimentation, third year 2021

In 2021, initial experimentation with projection mapping took place informally with third-year students. In order to introduce the students to the method of projection mapping onto 3D objects, a sphere was prepared for an in-class demonstration. A 1m diameter inflatable beach ball was skinned with paper-mâché to create a smooth white surface. This sphere was suspended from the ceiling in the departmental computer studio, and a mobile standard digital projector was pointed at the sphere. Students then experimented by projecting various existing animations, images, 3D CAD models and textures onto the sphere (Figure 2).

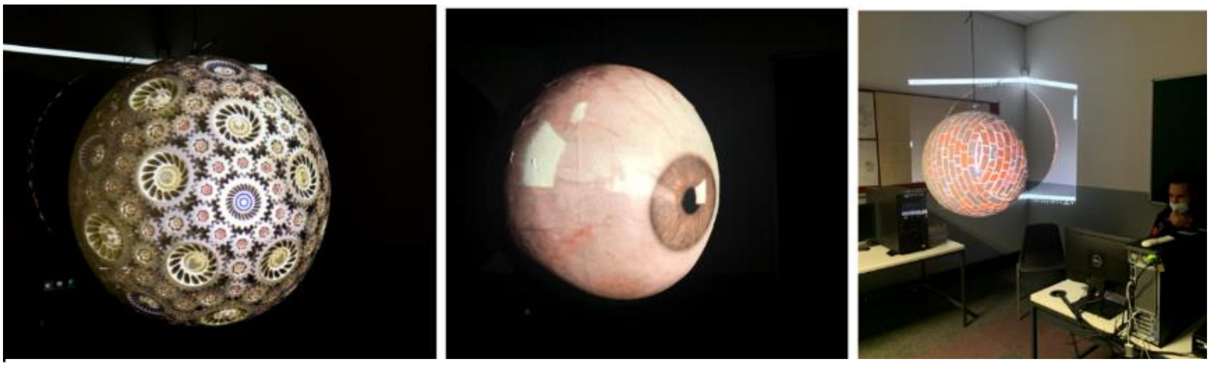

Figure 2: Projection mapping experimentation with suspended sphere (2021)

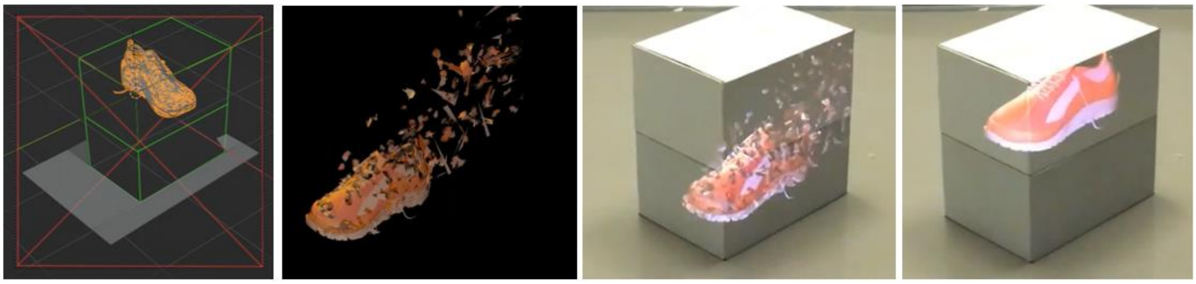

Figure 3: Student A shoe advertising concept (2022)

Building on the discovered potential of projection mapping, the 2022 third-year students, in a relatively open-ended brief, were tasked to develop an innovative product or display system that incorporated projection mapping. Because projection mapping offers the benefit of being able to change and adapt product surface finishes, students were required to incorporate animated or changing images into their outcomes. Students had the freedom to interpret the application of this brief, resulting in varying approaches. Student outcomes included a variety of new approaches to in-store product displays and product advertising. For example, Student A imagined an installation of shoeboxes (Figure 3) that, with the use of projection mapping, presented various animations (created in Blender) illustrating the range of products on sale. Similarly, Student B conceptualised how a projection mapping system could be used within McDonald's restaurants to creatively display the different flavours/brands of soft drinks they offer through a series of static and moving projections onto a white soda cup (Figure 4).

Figure 4: Student B McDonalds soda advertising concept (2022)

Student C designed a 2.5 m interactive sculpture/installation (Figure 5). In order to create the sculpture, the student used a handheld 3D scanner to capture a detailed 3D model of their head and face, saving it as an STL file. Using a series of software tools, including Papakura, which facilitates the transformation of 3D models into flat triangles, and the Decimate command in Blender, the 3D model was simplified into a more geometric polygonal form comprising a series of triangles. These simplified triangles were then printed, cut out, meticulously folded, and assembled to recreate the 3D sculpture. The final sculpture, measuring 2.5 meters in height, 1.6 meters in width, and 1.15 meters in depth, was crafted from 3mm corrugated cardboard. In order to enhance the visual impact of the sculpture, a standard overhead projector was positioned approximately 5 meters away, enabling the projection of a diverse range of images, videos, and textures onto its surface. This creative projection technique resulted in a captivating and visually engaging experience, yielding numerous interesting outcomes. Notably, this achievement found practical application as the sculpture served as a striking backdrop for the faculty's annual fashion show, further showcasing its successful integration into real-world settings.

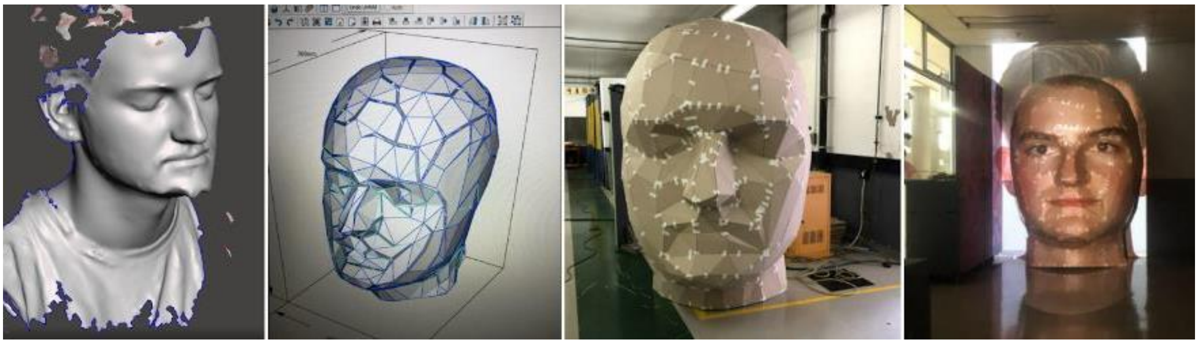

Figure 5: Student C 'Big Head' installation sculpture (2022)

Cycle 3: Mixed media identity portrait, first year 2022

Cycle 3 was facilitated at a first-year level in a digital-based module. The “mixed-media portrait” project has been run in the department for a few years, as a means of introducing the basics of bitmap manipulation and creating mixed-media compositions in open-source software, GIMP. Each year, students are tasked to create a mixed-media identity portrait (composite image) inspired by their personalities, backgrounds, and heritage. Traditionally, this project concluded with a 2D poster output of their portrait. In this case, the project went a step further, whereby the portraits were to be projected onto the large face sculpture, ‘Big Head’ from the previous cycle. This project formed part of an international collaborative project with the University of Cincinnati titled Art as a Catalyst for Global Understanding. The additional element of projection mapping involved an added level of complexity, whereby careful consideration of the alignment of their portrait photographs to a face template (Figure 6) was required during the file preparation phase to ensure accurate alignment with the sculpture. Figure 7 shows a selection of outputs showcasing the variety and quality of digital files created.

Third-year students were also invited to create projections for the sculpture. Student B moved a step past a static projection and developed multiple versions of their mixed media portrait (Figure 8), which were compiled into a slide show video. This creative approach allowed for the presentation of various mixed-media versions in a dynamic and visually engaging manner, enhancing the overall impact of the installation.

Figure 6: Cycle 3, Student D, process steps of aligning to face template (2022)

Figure 7: Cycle 3, selection of outcomes Students E, F, G (2022)

Figure 8: Student B Mixed media portrait variations and projection (2022)

Figure 9: Shoe pattern projection process of steps (2023)

Cycle 4: Shoe pattern, first year 2022-2023

The next project was, again, facilitated at a first-year level in the digital module, linked to a project completed in the students' core practical design module. The "pattern project" has been run in the department for several years, as a means of teaching design elements and principles of colour theory and pattern creation as well as the practical introduction to vector creation in open-source software, Inkscape. In previous years, students were tasked with creating colourful 2D patterns, which were digitally clipped into outlines of various clothing item outlines, such as Converse high tops and swim shorts. In 2022, the brief was adapted to incorporate and explore how projection mapping could elevate the complexity, accuracy, and applicability of this project, bringing the typically 2D digitally bound content into the 3D physical space. Students were tasked with designing a contemporary pattern in two colour schemes to be digitally mapped onto 3D triplex model shoes, which had been created in their core design practice module. Students were required to photograph their triplex model shoe (side view) and use the vector tools in an open-source vector creation software, Inkscape, to create a digital line drawing of their shoe, tracing the photograph. Patterns were then clipped into the areas of the shoe. These digital mock-ups were then projected onto the physical shoes (Figure 9). This project was run for two cycles, in 2022 (4a) and again in 2023 (4b).

Cycle 5: STH Installations, the second-year 2023

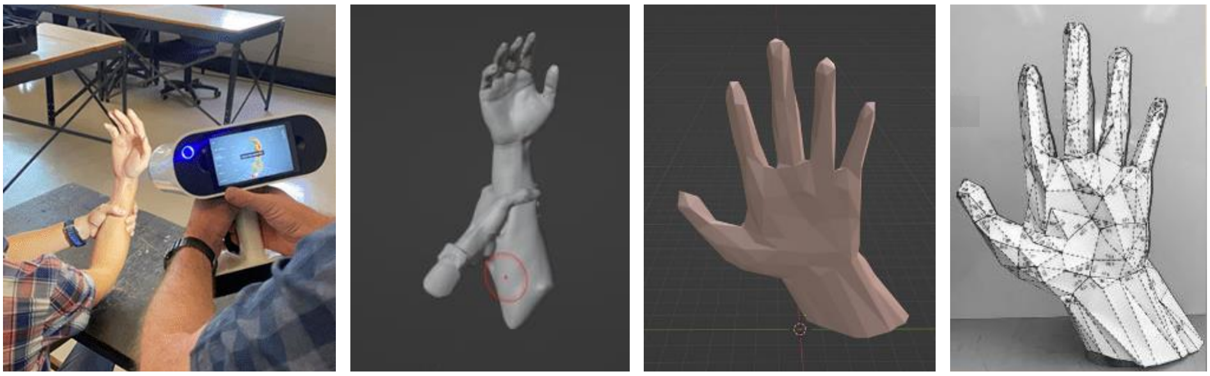

Figure 10: 3D scanning and modeling process (2023)

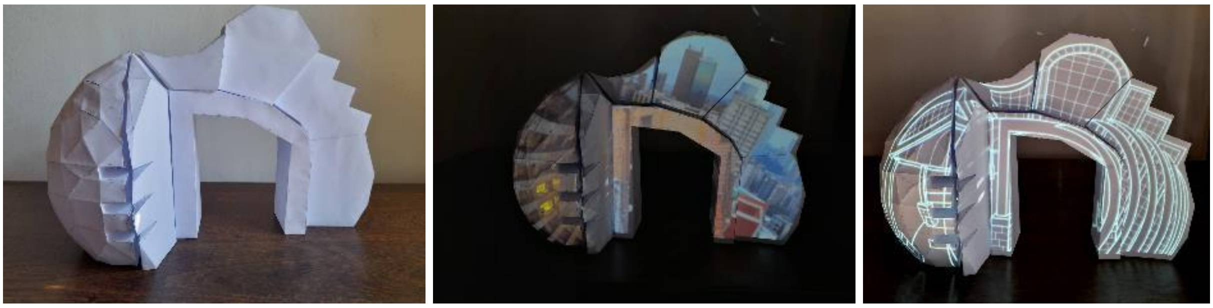

Figure 11: STH Installation projection mapping outcome (2023)

Building on what they learned in their first year (2022), in 2023, second-year students were tasked to create both static 2D images and motion videos that were presented in 3D environments using projection mapping. Students were tasked to design and manufacture a projection-mapped stage set for a School of Hospitality (STH) open day with the broad theme of 'advancing inclusivity'. Students were divided into four groups to develop large-scale free-standing cardboard models that were used as surfaces for digital images, animations, and videos to be projected onto. Similar to 'Big Head, ' the cardboard models were created by first generating a CAD model. This was done by either digitally modelling the form or using a 3D scanner that generated a model based on existing physical forms (Figure 10). The models were then put through a tessellation tool that simplified them into faceted forms before using further software that generated a 2D net of the tessellated model. These nets were then laser cut and used to physically build free-standing models to create a 'diverse landscape' that would be projected onto to create an immersive event environment. After creating their physical models, students went on to individually create vectors, GIFs, photograph collages, and videos that were projected onto the 3D surfaces of their models (Figure 11).

Reflections and discussion

A key component of action research is the method of reflection (Clark et al. 2020). Research is primarily concerned with the generation of knowledge and action research generates *reflective* knowledge in practical educational contexts, allowing educators to learn through their actions to develop personally or professionally (Clark et al. 2020). Encouraging students and lecturers to reflect on their actions and experiences enables a better understanding of those experiences and the consequences of those actions (Clark et al. 2020). At the end of each project, students were asked to document their personal experiences and reflections on the project. Key findings from these reflections are presented below.

Student reflections and feedback

Most students found projection mapping to be an effective way of realising their designs. It served as a method of envisioning what a final product would look like and allowed for multiple colours, surface finishes, and graphics to be illustrated on their products. While multiple students described the projection-mapped images to be realistic, the technique was also criticised for only being somewhat realistic or not realistic at all, with the projected image being difficult to align with the actual 3D models. While not all outcomes were successful, multiple students reported finding the projections an effective way of developing their design skills and learning more about the importance of proportions and scale. Students reported that the incorporation of projection mapping within a design brief added a "creative element" to a project and was described as "exciting" and "interesting" and evoked new perspectives. The use of projection mapping made their designs "come alive" and "encouraged a sense of accomplishment". The technique was viewed as a successful way of engaging with the work their peers had created. This feedback illustrates that the incorporation of new and immersive technologies can also be viewed as an effective way of improving student engagement. Students also reflected on how projection mapping added value to the creative process. One student speculated on the method being used as part of the design ideation process, realistically illustrating digital developmental work in the physical realm before adjusting and developing a design. Using projection mapping reduced prototyping materials and costs and allowed for rapid design iterations to be made within the design process. When speculating on how projection mapping could be successfully used within the South African Industrial Design industry, students remarked on various aspects. The accessibility and affordability of projection mapping was seen as a benefit that could help designers save on having to create multiple product models and instead make use of this technology to illustrate multiple product finishes on a single prototype. It was also described as a way of elevating the presentation of design concepts to clients. It was described as a tool that could aid designers in easily changing and adapting design concepts and enable the creation of immersive and convincing environments for an audience.

Lecturer's reflections

Conducting a project at the first-year level presents its challenges as students are still in the process of acquiring fundamental skills in prototyping, digital work, and photography. Reflecting on the mixed media portrait project (Cycle 3), we believe that projecting still images onto the structure was suitable for a first-year level, where the focus was primarily on file preparation and execution while learning the basics of bitmap manipulation. Providing a template to which the students could align their work, proved successful, with most projections aligning successfully. However, reflecting on Cycle 4, the shoe pattern project relied more heavily on the quality and level of detail of the original triplex model shoe and the accuracy of subsequent stages of photography and vector creation. Students who had shoe models with limited surface area, as seen in Figure 12, faced challenges in achieving effective projections and pattern application compared to those with more surface area. Additionally, instances where students did not follow instructions, such as capturing exact side-on photographs of the shoe, did not achieve effective projections, as the image did not align with the model accurately, as seen in Figure 13. Therefore, in future iterations, one might consider using a "universal" sneaker/boot for all students and provide a template as done in the mixed media portrait to allow for more effective projection outcomes.

Figure 12: Unsuccessful projection due to limited surface area (2023)

Figure 13: Unsuccessful projection due to misalignment (2023)

On a second-year level, the STH installation project was used as a means of introducing further design skills such as animation and video editing. The integration of projection mapping is intended to increase the engagement of students, giving them the opportunity of seeing their design outputs being presented in a public setting outside of their departmental studio. Applying a general theme to the project allowed the students to engage with design outcomes on a more conceptual level. Along with training in new hard skills, students also explored more around how images and videos could be used as a form of effective visual communication. Along with this, the project also introduced a wider scope of potential advantages and uses that projection mapping could offer, making it a steady progression from what was undertaken in the first-year projects. The combination of group work and individual outputs was effective, as four successful large-scale models were designed as projection surfaces. Individual outputs of images and videos to be projected were not all successful, however, due to varying skill levels. Not all images were proportioned correctly to line up with the model and the quality of images and videos generated were insufficient in some cases. Therefore, images and videos for the STH open day exhibit were carefully selected. With a large variety of outcomes, this made it possible to create an engaging and immersive display.

Conducting the projection-mapping project at the third-year level provided an opportunity to explore a wider range of project outcomes, varying in their complexity and feasibility for implementation. As these students were in their final year of studies, they were granted the freedom to define their individual project directions. This approach resulted in a diverse collection of approaches and applications, which may not have been explored if the lecturer had predetermined the project focus. The open nature of the brief also allowed for a wider exploration of potential projection mapping applications to emerge.

Conclusion

As the Industrial Design discipline changes and adapts to the technological shifts driven by Industry 4.0, higher education institutions need to adjust their curricula accordingly. By integrating emerging technologies such as projection mapping into design projects, students can acquire the essential skills and knowledge necessary for a rapidly changing professional environment. Our findings outline the positive impact of using projection mapping as a pedagogical tool to enhance student engagement and learning outcomes.

Furthermore, our study contributes to the discourse on how the integration of advanced digital tools, such as projection mapping, effectively prepares students for the challenges and opportunities presented by 4IR. Specifically, our findings recommend the introduction of projection mapping in the initial years of study, allowing students to become familiar with this technique. As students progress into their third year of study, they can apply this understanding and use projection mapping in more advanced and creative ways.

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