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The Implementation of 3D Printing Prototype Making in Industrial Design Final Year Student Project

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Abstract

Technological innovation has accelerated rapid manufacturing today. The adaptation of 3D printing has spread in many products manufacturing that proves the increasing of productivity and has fulfilled the requirements in industrial revolution 4.0 (IR4.0) towards digitalization. Industrial design students here in Polytechnic Ibrahim Sultan are encouraged to explore prototype making by using 3D printing to develop creativity through this product design process. During this time, product development in industrial design was practiced manually using standard techniques namely sketch, presentation drawing, technical drawing, rendering, prototype, and model making. This research was conducted to provide a review of the implementation of 3D printing in industrial design final year students' prototype making and to analyze the impact of the 3D printing implementation on CLO achievement. The research method of this study is qualitative research, where group discussion has been conducted in a focus group. Generic process of CAD has been used in the development process consists of eight stages which include CAD, STL convert, File transfer to machine, Machine setup, Build, Remove, Post Process and Application. The findings of this research indicate the advantages of 3D printing that elevates students' skills from traditional methods to technology-driven methods, improvement of CAD drawing techniques and enhancing skills for lifelong learning. Based on this result, Course Learning Outcome (CLO) for DVI50144 (Industrial Design 4) session 1 2022:2023 are increased compared to session 2 2021:2022 for CLO1 (Cognitive) 6.5%, CLO2 (Psychomotor) 3.0%, CLO3 (Psychomotor) 2.5% and CLO4 (Affective) 17.5%. The adaptation of 3D printing in Final Year project (FYP) allows students to explore the challenges of 3D printing in industrial design and enhance their creativity to become industrial designers in future and the effort of lecturers to improve the skill in 3D printing.

Keywords: - 3D printing, prototype making, industrial design, Final Year Project

1. Introduction

The Industrial Revolution 4.0 (IR4.0) that hit the world today has witnessed the implementation of digitalization in the various levels of education in Malaysia. Along with the development of technology and innovation, Malaysia is seen refusing to fall behind in the flow of development that can improve the capabilities, skills, and expertise of its population. This phenomenon is also aligned with the executive summary of the Malaysian Education Development Plan 2015-2025 (Higher Education) or PPPM (PT) through a new system of higher education that focuses on success, beyond input, as well as using technology and innovation to meet needs and improve student learning experience. The teaching and learning methods driven by IR 4.0 have also given a point of change to the educational landscape of TVET in Malaysia, especially in the Diploma of Industrial Design, Polytechnic Ibrahim Sultan. Changing approaches from traditional methods to methods of use of technology – 3D printing in the development process of prototype final project students have driven toward monitoring skills along with the National 4th Industrial Revolution (4IR) that promoting a culture of innovation and creativity in society that emerged from the evolution of technologies. Polytechnic is seen as the country's leading TVET field leader with a graduate market capability achievement rate

of 96.27% according to the 2022 KPI Performance Report issued by the Department of Political Education and Community Colleges (JPPKK) on 17 January 2023. To face the challenges in the development of IR 4.0, students in the field of industry design must master the skills that represent IR 4.0 that can improve their marketability in the future. Hence, the possesses of 3D printing processes is important in rekindling of the powerful pedagogy of hands-on learning and to deepen the educational approach to traditional subjects (Pai, Gourish, Moger, & Mahale, 2018). According to Chun (2021), 3D printing is important and necessary to be adapted in the curriculum to be able to create the expertise. Thus, will impact on the education of future product designers (Lindley, Adams, Beaufoy, & McGonigal, 2016). Despite this importance, this study was focused on final project prototype design development to demonstrate creativity in utilizing 3D printing and both knowledge of manufacture and theoretical understanding by this new technology. Accordingly, in this research the term 3D printing (3DP) is used instead of some cases or program used AM (Additive Manufacturing) technologies.

1.1 Research Objectives

1. To provide a review of the implementation of 3D printing in industrial design final year students' prototype making.
2. To analyze the impact of the 3D printing implementation on CLO achievement.

1.2 Research Questions

1. What is the review of the implementation of 3D printing in industrial design final year students' prototype making?
2. What is the impact of the 3D implementation on CLO achievement?

2. Literature Review

2.1 3D Printing in Design Education

3D printing is an additive fabrication process that can turn digital computer-generated geometry into physical objects using a variety of materials through a layer-by-layer building process (Micallef, 2015). Meanwhile, Li & Zhao (2016) stated 3D printing technology is the main form of "additive manufacturing". It works by transferring a product's design and shape into a computer model to create a finished object. Fig. 1 shows a 3D printer used in the Industrial Design Department, Polytechnic Ibrahim Sultan. The process works by starting with the base layer and then building up each additional layer until the full objects have been completed (Hausman & Horne, 2014). According to Mcculloch (n.d.), 3D printing was invented by Charles Hull in 1983, where the first 3D model was a printed cup (Hull, 2015). 3D printing is an innovative technology and shall have a huge impact on the future of society because of its emphasis on creating something quickly (Gibson, Rosen, Strucker, & Khorasani, 2021). Ford & Minshall (2019), stated the benefit of adapting 3D printing in universities to support student learning in the lab or classroom and as a medium for visual learning aids too. A variety of benefits are being identified by adapting this technology into teaching. Berry et al., (2010) found 3DP can facilitate learning, develop skills, and increase student engagement through creativity. Learning by making has a long-established history in design education as products must be taken beyond concepts through a repetitive process of various testing and development to produce functional, aesthetic, and commercially manufactured products (Loy, 2014). For a generation that has mainly been brought up immersed in the virtual world, 3D computer-based modelling is the current level of sophistication in product design education rather than spending time in physical workshops like previous generations. Lindley et al., (2014) mentioned that manufacturing through 3DP reduces the complexity of traditional manufacturing through a design process where students can explore creatively, which opens new possibilities by realizing the virtual and real worlds through a design project for Industrial Design (IDE) students.

Fig. 1. 3D-printer used in Industrial Design Department, Polytechnic Ibrahim Sultan

2.2 Implementation of 3D Printing in Industrial Design Final Year Project

Realizing this benefit, final year students of Industrial Design at Polytechnic Ibrahim Sultan have demonstrated their prototype making using 3D printing appropriately for the purpose of the curriculum syllabus. They are given an individual project to develop a product design and instructed to follow the Design Council's Double Diamond Design Process, as shown in Fig. 2, for a model-based orientation in the final project. This model was developed by the Design Council in 2005 and is called a 4D model because the name of each phase starts with a 'D': *discover, define, develop, and deliver* (Tschimmel, 2012). This model is graphically based on a simple diagram that describes the divergent and convergent stages of the design process.

Fig. 2. The Double Diamond Design Process developed by the design council (Gimenez & Johnson, 2020)

The Double Diamond Process became a reference in the project outline that encouraged students to come up with imaginative, user-centered solutions to social or product issues. Hence, it also achieves this by incorporating and valuing 3DP as a mechanism to replicate commercial processes (Lindley, Adams, Beaufoy, & McGonigal, 2014). As a final year project, it was an opportunity to encourage students by demonstrating the management of the final project development process from preliminary design to the construction of a product design prototype. Referring to the Course Learning Outcomes (CLO) of Industrial Design 4 (DVI50144), CLO1 (Cognitive) analyzes basic research techniques, organize, and analyze data to generate a design concept and proposal. CLO2 (Psychomotor) creates realistic ideas into sketching and mock-ups by applying the right design process methods. CLO3 (Psychomotor) construct a model, scale model, or prototype precisely referring to the technical drawing, mock-up, and 3D rendering. CLO4 (Affective) present a high-quality presentation highlighting the product design. CRR (Course Review Report) result summarized the increment of achievement in DVI50144 session 1 2022: 2023 compared to session 2 2021:2022. The number of CLO's increments are rising after students implemented 3D printing to produce the prototype making for the Final Year Project (FYP) compared than students in session 2 2021:2022, that used traditional and manual method. The increment of CLOs concluded that students are experienced and have developed the knowledge and skills to enhance their understanding of industrial design. They were given a final project brief: 'Construct a 3D design in the form of a model, and prototype based on your selected design using 3DP'. This includes the ability to produce designs such as 3D product prototypes driven by CAD packages. Comprehensive technical skills are required as a part of the design process, which become a need for life-long learning and demonstrate the ability to practice as product designers (Lindley, Adams, Beaufoy, & McGonigal, 2016).

3. Methodology

The generic process of CAD to part showing eight stages as referred in Fig. 3 which consists of (1) CAD (2) STL convert (3) File transfer to machine (4) Machine setup (5) Build (6) Remove (7) Post- process (8) Application (Gibson, Rosen, Strucker, & Khorasani, 2021). It summarized, at early stages of the prototype making process, it may only require rough parts because of the speed they can be fabricated, but later stages of the process, parts may require careful cleaning and postprocessing such as sanding, surface preparation and painting. It develops on prior learning of the design process, a knowledge of manufacturing and the skill base of CAD (Solid works CAD Package) (Lindley, Adams, Beaufoy, & McGonigal, 2014). This project development process was dependent on students' creativity and skills through the implementation of new technologies, computers, and additive manufacturing (Lindley, Adams, Beaufoy, & McGonigal, 2014). The construction of 3D design form model or prototype had two distinct benefits: Firstly, it allowed students to indicate their creativity in making a form which previously impossible and secondly, the final product or prototype design represented the ability of enhancement skills and creativity that could be useful in promoting themselves as future product designer.

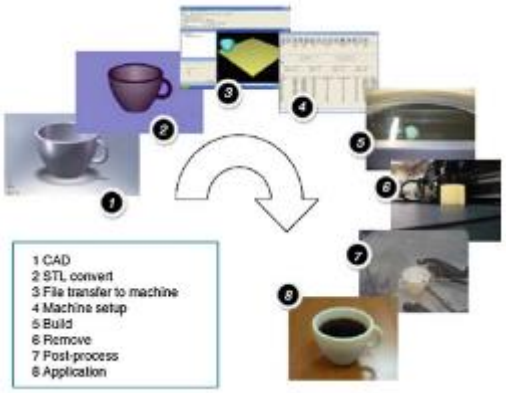


Fig. 3. Generic process of CAD to part, showing eight stages (Gibson, 2021)

The beginning development of prototype parts can be produced with model software that is able to determine the external geometry form. 3D printing can be ideal to use since the model /prototype is lightweight, fast to print and install (Hansen, Lundh, & Chen, 2014). This research is focusing on the usability and accessibility of SolidWorks that was implemented by Industrial Design students to develop the 3D prototype model parts. According to Adamczak & Graba (2020), the proper CAD program helps designer visualized the model of a new industrial form. However, the computer package used needs to be accessible, efficient and user friendly (Hansen, Lundh, & Chen, 2014). It reflects the implementation of 3D printing in prototype making give a positive impact to the academic achievement overall.

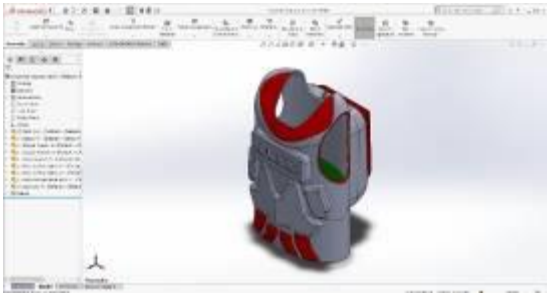
3.1 Second Stage – STL Convert

Gokhare & Raut (2017) claimed Charles Hull was a pioneer of the solid imaging process known as stereolithography and the STL (stereolithographic) file

format was now still widely used in 3D printing. STL refers to a format that is used to transfer information from CAD software to 3D printer (C Iancu, D Iancu, & Stăncioiu, 2010). Meanwhile, Gibson et al., (2021), describes STL format able to describes the external closed surfaces of the original CAD model and forms the basis for slices calculation.

3.2 Third Stage - File Transfer to Machine

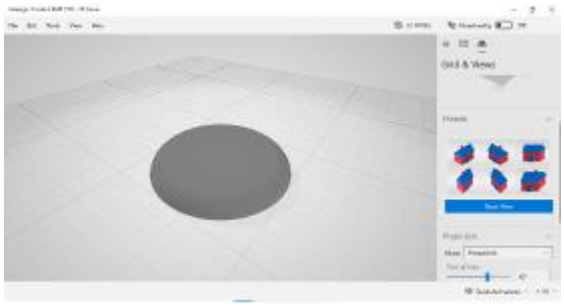
The STL file describing the part must be transferred to the 3D printing machine (Gibson, Rosen, Strucker, & Khorasani, 2021). According to Gokhare & Raut (2017), before printing a 3D model from an STL file, it must be processed by a piece of software called a slicer, which converts the 3D model into a series of thin layers. Complete model construction can take from several hours to several days, depending on the method used, the model's size, and the complexity of the model. Fig. 7 shows the comparison of time allocation for completing the 3DP processed product part depending on its size and complexity developed by Ahmad Imran Hakim bin Shahril for the final year project in 2022. Part (a) took 13 hours and 56 minutes, while part (b) took 7 hours and 56 minutes.



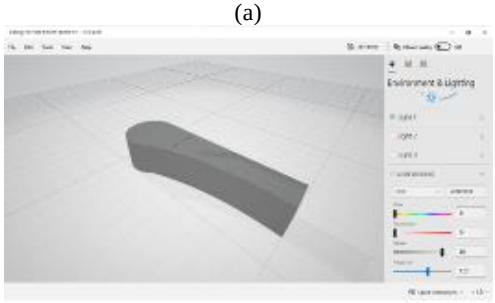
(a)

(b)

Fig. 4. Prototype parts using SolidWorks – developed and implemented by Ahmad Imran Hakim bin Shahril for Diploma Industrial Design Final Year Project, 2022



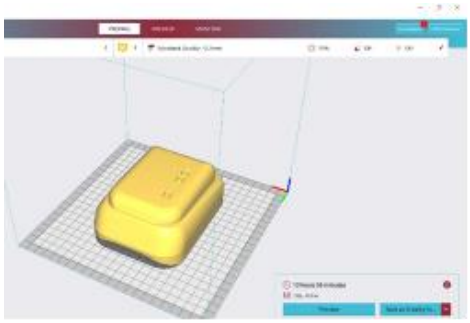
(a)



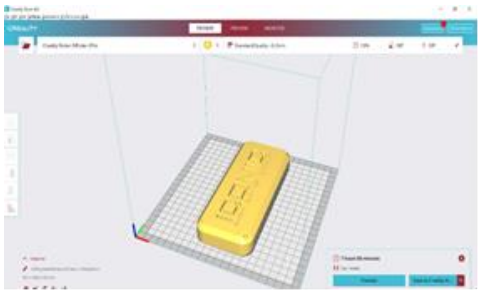
(b)

Fig. 5. Prototype parts convert to STL – developed and implemented by Ainursofea binti Razak for Diploma Industrial Design Final Year Project, 2022

Fig. 6. Various stages of build process (Hiemenz, 2011)



(a)



(b)

Fig. 6. (a) and (b) Time allocation depending on the form complexity-developed and implemented by Ahmad Imran Hakim bin Shahril for Industrial Design Final Year Project, 2022

3.3 Fourth Stage – Machine Setup

Machine setup, or prep machine, allows the system to automatically feed the material filament to the extrusion head. The base must be inserted first, followed by the file selection to begin building the model. The setting would relate to the build parameters, namely material constraints, energy source, layer thickness, time consumption, etc. (Gibson, Rosen, Strucker, & Khorasani, 2021).

3.4 Fifth Stage – Build

Building the part is mainly an automated process, and the machine can largely carry on without supervision (Gibson, Rosen, Strucker, & Khorasani, 2021). During this process, it requires only slight supervision of the machine to keep it free from any errors like running out of material, power, or software disturbances, etc. Usually, to build a model or prototype using 3DP, the filament is chosen based on the design profile. Ahmad Imran Hakim bin Shahril was concerned about using thermoplastic polyurethane (TPU) to explore a new form of Safety and Rescue (SAR) jacket. An innovative element of the proposed form is to enhance the ability of elasticity compared to a conventional process (Parada, Rosa, & Mayuet, 2021). Meanwhile, the mock-up proposed by Ainursofea binti Razak uses silicate-reinforced polylactic acid (PLA) to visualize the free-standing mock-up structure of a self-service kiosk. The various filament options will allow students to investigate their various capabilities and their impact on the printing temperature, particularly in the 3DP process.

3.5 Sixth Stage – Remove

The parts need to be taken out after the building process is finished (Gibson, Rosen, Strucker, & Khorasani, 2021). This can involve interacting with the machine, which might have safety interlocks to make sure, for instance, that the operating temperatures are low enough or that there are no actively moving parts.

3.6 Seventh Stage – Post-Process

Post-processing refers to removing disposable support material after the part is completely done. It can be done by either washing or stripping away the support material that held the part in place. Hiemenz (2011) also mentioned the removal depends on the type of material used for the support. For soluble support material, it is removed in a tank via an agitated water-based detergent solution. However, for breakaway support material it was removed manually by twisting, breaking, and scraping the support material from the part.

3.7 Eight Stage – Application

Application step is the final step where the parts or product may be ready to be used. It may also require additional treatment before they are suitable for use. (Gibson, Rosen, Strucker, & Khorasani, 2021). cited priming and painting to provide a desired surface, texture, and finish. Fig. 8 shows the painting process for surface treatment as implemented by Ahmad Imran Hakim bin Shahril before assembling with other parts and accessories to form his complete prototype.

4. Finding and Analysis

Seven students were chosen to participate in a group discussion to get their thoughts and opinions. To gain advantage from the use of 3D printing in industrial design education, the survey results are presented and analyzed in this part.

4.1 Transition from Traditional to Technology-Driven Method

The adaptation of 3D printing in the process of prototyping among students of the final year of the industrial design diploma is one of the latest approaches in the newly introduced after realizing the importance of the 3D Printing in elevating students' skills towards the Industrial Revolution 4.0. Traditionally producing prototypes that involve long processes and time-consuming in workshops have shown different results and outputs compared to prototyping using 3D printing. This comparison shows a significant outcome from the quality and total angle that is estimated to produce a prototype. Student A commented: "Traditional methods of making prototypes take a long process and require lots of time in a practical workshop. It requires manual skills and using conventional model making foam that is hard to turn into the desired form. Later, I found 3D printing to visualize the prototype-making process and shorten the process." The transition from traditional methods to technology-driven methods is important to elevate the skills of students at higher institutions and prove their capability to immerse themselves in technology. Meanwhile, student B noted the traditional making techniques are no longer reliable and undertake so much work: "I believe that stakeholders no longer find traditional method making techniques to be relevant or useful." According to responses, 3D printing is a useful technology-driven technique that enables students to create the intricate models they envision.

Fig. 8. Post-Process prototype – developed and implemented by Ahmad Imran Hakim bin Shahril for Diploma Industrial Design Final Year Project, 2022

Fig. 9. Painting for surface treatment – developed and implemented by Ahmad Imran Hakim bin Shahril for Diploma Industrial Design Final Year Project, 2022

Fig. 10. Painting for surface treatment – developed and implemented by Ahmad Imran Hakim bin Shahril for Diploma Industrial Design Final Year Project, 2022

Fig. 11. Prototype produced using traditional method-developed and implemented by Vaishnavii Selvam for Diploma Industrial Design Final Year Project, 2022

Fig. 12. Finished SAR (Safety and Rescue) jacket prototype – developed and implemented by Ahmad Imran Hakim bin Shahril for Diploma Industrial Design Final Year Project, 2022

4.2 Improvement of CAD Drawing Techniques

Industrial Design course train students in 3D drawing that is useful to print with a 3D printer. Student C said: “I become more proficient in CAD drawing skills such as SolidWorks, KeyShot and Creality.” However, Student D commented: “Proficient in 3D modelling software can fully express the idea, and ultimately the 3D printer will turn the idea into the model.” The replies indicate that learning computer control language and using modelling software proficiently offers an edge to actual production without technical restrictions.

4.3 Enhancing Skills for Lifelong Learning

From this research, the result indicates possessed in 3D printing skills can improve students’ lifelong learning skills. According to Student E: "Practicing my 3D printing skills during learning times has helped me become more independent, proactive, and capable of making plans, as well as inspired to become more creative and forward-looking mindset," It is important to realize the planning ahead before implement something. Meanwhile, Student F said: “I was totally ready to welcome the future of “smart factory” with more innovative ideas as Industry 4.0 summarized to contain nine pillars that evokes to digitalize manufacturing.” This overview scenario also encourage Students G mentioned: “I realized 3D printing technology will become important in future that brings chances to make products independently without concerning finance issues.” According to responses, 3D printing has embodied personalized and intelligent features that make personalized design and manufacture possible. Users are attempted to create their own customized items by straightforward processes and lower expenses.

4.4 Increment of CLO Achievement

The approach to the production of the Final Year Project prototype (FYP) using the 3D printing method among students of the final year of the Diploma of Industrial Design, Polytechnic Ibrahim Sultan on session 1 2022:2023 has successfully demonstrated an improvement in the CLO achievement of the DVI50144 (Industrial Design 4) course compared to session 2 2021:2022. According to Course Review Report (CRR), CLO3 (Psychomotor) has shown a 2.5% increase which shows 3D printing is an effective method to help improve the skills of students in producing better and perfect prototypes. However, the 3.0% increase involving CLO2 (Psychomotor) demonstrates that the digital method helps the comprehensive design production process to be more technically realistic. Meanwhile, CLO1(Cognitive) also draws 6.5% increment and CLO4(Affective) shows the increment 17.5% compared to session 1 2021:2022. It reflects the implementation of 3D printing in prototype making give a positive impact to the academic achievement in overall learning outcomes.

Fig. 13. Comparison percentage of CLO achievement for DVI50144(Industrial Design 4) session 2 2021:2022 and session 1 2022:2023

5. Conclusion

Overall, from the findings it was found that the use of 3D printing has helped students to understand, implement and apply technology-driven in the production process of the Final Year Project prototype (FYP) final year students of the Diploma of Industrial Design, Polytechnic Ibrahim Sultan. The adaptation of 3D printing is seen able to give exposure to the adaptation of manufacturing technology of IR 4.0 and towards globalization. The use of 3D printing has also proved the advantages of technology as a medium that helps improve student performance from an academic perspective, the transition of the learning medium from conventional to technology-driven methods as well as lifelong learning. Regardless, the use of 3D printing was also seen to demonstrate an improvement in CLO for the DVI50144 (Industrial Design 4) course based on a comparison of the achievements of session 2 2021:2022 to session 1 2022:2023.

6. Recommendations

3D printing technology brings opportunities in industrial design. There is always a challenge from the advantages. The speed of the production depends on the complexity of the design. To finish with specific design, duration always becomes a challenge in dealing with deadlines. Development of prototypes using multi-color and multi-materials also challenge that must be concerned to create a variety of product. In addition, the next challenge is minimizing the use of the raw material as the support structure materials are unrecyclable. As advanced technology, staff in higher institutions such as in Polytechnic Ibrahim Sultan should be trained to improve their skills in smart manufacturing including 3D printing to become more high-skilled professional talents to shape the future generations towards IR 4.0.

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