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Integration of 3D Printing as a Learning Tool in Engineering Education- A Review

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***Abstract**: Engineering students at undergraduate level learn basic concepts, design, and construction through lectures, computer simulations and conventional machining technique. However, the current curriculum and course contents do not expose students to emerging 3D printing technologies that opens door for new design and construction solutions with greater efficiency. Various authors have proposed the inclusion of 3D printing in the engineering courses due to its rapid prototyping. A brief description of applications of 3D printing in civil, electrical and mechanical engineering are presented in this paper. Through comprehensive reviewing of the applications of 3D printing technology, its integration to engineering curriculum will be appropriate for learning and teaching of engineering courses. As a result of this study, it has been understood that 3D printing should be implemented in engineering education and recommendations were made for genuine policies for introduction of 3D additive technology to engineering education system.*

Key Words; *3D printing, additive technology, Engineering education, Fused Deposition Modelling, Selective Layer Sintering, Stereolithography*

1.0 Introduction

The technology of 3D printing has been around for many years, and as the patents for 3D printing have expired, the costs of 3D printers have been slowly decreasing (Yu-Hung, 2017). The knowledge of this technology is essential for students who want to secure job opportunities in Engineering firms after they graduate. It is crucial for students to have the ability to familiarize themselves with and explore this emerging trend in technology to foster innovation, creativity and prepare for future careers and challenge (Talal, Milan, Yi, Michael, Thomas, and Falko, 2020).

The primary emphasis in science and mathematics education is on teaching theoretical concepts rather than real world applications (Corum and Garofalo, 2015). Hands-on activities can be integrated into the technology and engineering education to enhance design procedures and foster core competencies (Yu-Hung, 2017). The use of digital fabrication technologies to support architecture and engineering disciplines in prototyping is far from new. The integration of digital technologies like 3D into teaching has revealed various advantages such as facilitating learning, creativity, and skill development; enhancing students' attitudes towards Science, Technology, Engineering, and Mathematics (STEM) subjects; and increasing instructors' interest and engagement (Simon and Tim, 2018).

In a fast-growing and complex world, training young people with the right skills and technology for the future is very important. Digital transformation and emerging technologies nowadays mean students in STEM related courses must be well equipped with a wide range of modern, applicable skill. Students need the right skills to succeed in the world they will graduate into (UltiMaker, 2022). The project involving a 3D printer provided schools with a great chance to delve into creative methods of instructing STEM subjects, sparking students' interest and enhancing the curriculum (Education, 2013). Figure 1 shows various sectors of application of 3D printing.

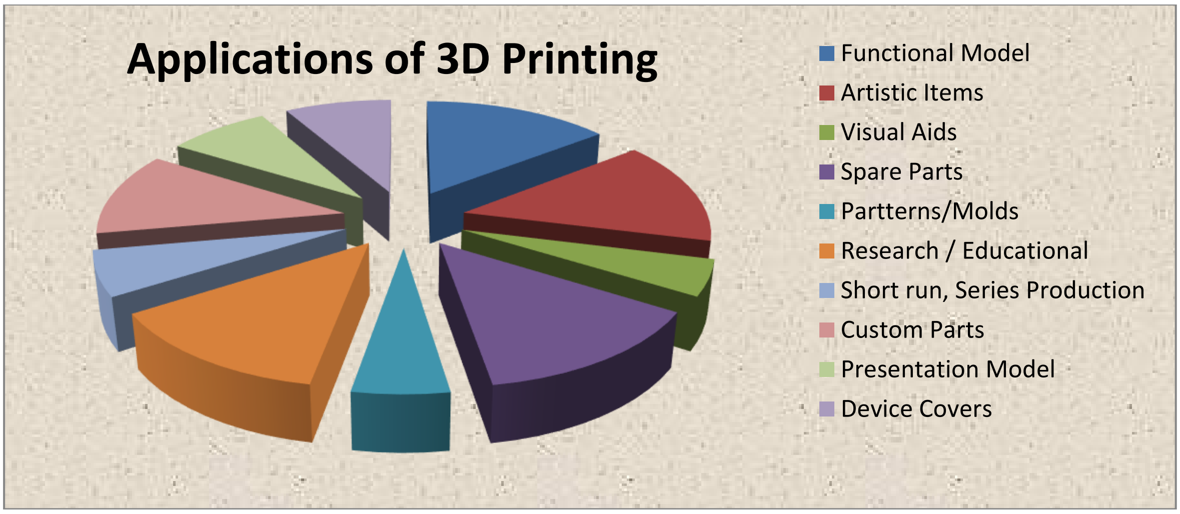

Figure 1: Applications of 3D Printing

Technology and engineering education enhance national competitiveness and drive economic growth by focusing on problem-solving, innovation, and design (Paul, et al., 2014). Many countries are exploring ways to integrate 3D printing into their curricula to cultivate engineering and technology professionals and boost national competitiveness. The use of this technology is becoming increasingly popular in manufacturing, education, and various other sectors (Yu-Hung, 2017). The Federal Ministry of Education has to encourage polytechnics and universities to focus on applications of new technology

Technological and engineering education now extends beyond traditional coursework, actively engaging students in constructing knowledge. Hands-on activities and product creation play a crucial role in this active learning process. 3D technologies support these efforts by providing new opportunities for knowledge representation and exploration in diverse ways.

2.0 Process of 3D Printing

3D printing is an additive manufacturing technology that creates three-dimensional solid objects by depositing successive layers of material based on a digital file, eliminating the need for cutting tools or molds (Lukáš and Oldřich, 2017). Additive manufacturing (AM) is a technology that creates three-dimensional products by depositing successive thin layers of material, typically ranging from 0.001 to 0.1 inches in thickness, until the final product is formed (Mohsen, 2017).

The technology is widely applied in industry to produce prototypes faster than traditional methods. It has started replacing conventional manufacturing processes in some situation like injection moulding. The term "3D printing" encompasses a wide range of processes and technologies, offering a full spectrum of capabilities for producing parts and products in various materials (Dave and Sunasara, 2015). The most common technologies, materials, and processes used in 3D printing are detailed in Table 1 (Mohsen, 2017).

Table 1: Types of AM Technologies

Types of 3D printing	**3D-Printing**	**Fused Deposition Modelling (FDM)**	**Selective Laser Sintering (SLS)**	**Stereolithography (SLA)**
Material	Glue, Ink, Powder	Plastic	Plastic	Plastics, Ceramics Metals
Process	Normal printing	Heating and defusing	UV/ Light is traced over Photosensitive pool of liquid	Laser edge out pool of liquid

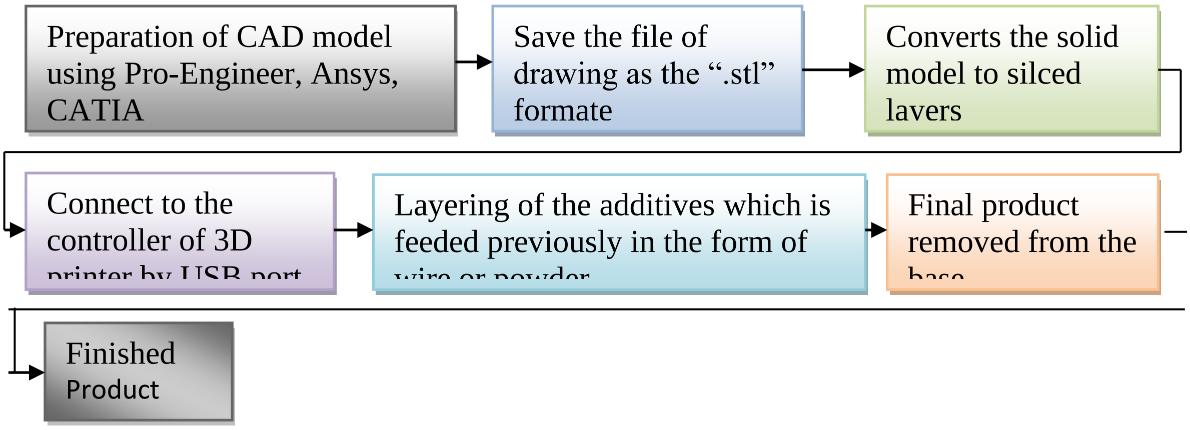

Figure 2: 3D Printer Flow Diagram

3D printing is fundamentally different from conventional manufacturing methods. Figure 2 Illustrates the manufacturing process of additive technology (Dave and Sunasara, 2015).

3.0 3D Printing and Engineering Education

An essential component of engineering education in polytechnics and universities is the incorporation of practical experiences, such as Industrial Training (IT), the Students Work Experience Programme (SWEP), and final-year projects, into the curriculum. This enables students to relate and get familiar with future careers and challenges. Previous research shows the importance of the inclusion of 3D technology and its integration into the engineering design process. Engineering design and construction process is as a result of government and customer needs, not Engineers' imaginations and this poses many challenges to students.

To meet and fulfil customers' needs, engineering students must learn to adopt the customers' perspective and critically assess how to solve problems in the most effective manner (Brophy, Klein, Portsmore, and Rogers, 2008). A strong skill is highly required by engineering students in problem-solving, communication, research and presentation (Nirmal, 2021). Abstract scientific concepts can often be challenging for students to grasp, which can hinder their learning performance (Corum and Garofalo, 2015). 3D printing technology can help students gain procedural knowledge through modelling and teach them how to solve problems by applying scientific and design principles (Kuen, Hsien-Sheng, Yu-Shan, Yu-Hung, and Ying-Tien, 2018).

3D printing is one of the fastest-growing technologies, significantly impacting the manufacturing sector, daily life, healthcare, and the global economy. Its rapid advancement continues to transform various industries and aspects of everyday life (Hirpa and Ove, 2021). The education sector is no exception for this transformation; its quick prototyping characteristic is effectively used in supporting modelling during engineering design process (Kuen, Hsien-Sheng, Yu-Shan, Yu-Hung, and Ying-Tien, 2018). On one hand, there is a significant interest and influence in incorporating the science and technology of 3D printing into existing engineering curricula. This integration aims to equip graduates with the necessary competencies in their field, enabling them to acquire and adapt to digital transformation (Hirpa and Ove, 2021).

Though, present engineering curriculum is well structured, students can solve various problems in engineering textbooks and yet they faced challenges during the college to career transition. Integrating 3D printing into various engineering education fields is believed to effectively help students understand numerous theories and principles. It also aids in modelling and optimizing processes during model construction.

Using 3D printing, new prototypes with complex geometries and internal structures can be created by engineers, and find solutions to problems without leaving laboratories or working environments. It fosters collaboration among peers and facilitates the creation of rapid prototypes and end-use parts. This collaborative environment and hands-on experience are invaluable for students as they prepare for their future careers. (Adam, 2019). 3D printing can indeed be applied across all engineering disciplines, including mechanical, electrical, civil, biomedical engineering, and more. This versatility makes it a powerful tool for enhancing education and preparing students for diverse fields. The advantages 3D printing in engineering education can be summarized as follows (Issah, Waleed and Hayder, 2019);

(i) **Enhanced Understanding**:
  - **Hands-On Learning**: 3D printing allows students to create physical models of complex concepts, making abstract theories more tangible and easier to understand.
  - **Visual Aid**: It provides a visual and tactile aid that can help in comprehending intricate designs and structures.

(ii) **Skill Development**:
- **Digital Fabrication**: Students gain experience with digital design software and 3D printers, which are valuable skills in modern engineering fields.
- **Technical Proficiency**: It helps students develop technical skills in areas such as CAD (Computer-Aided Design) and CAM (Computer-Aided Manufacturing).

(iii) **Innovation and Creativity**:
- **Creative Problem-Solving**: 3D printing encourages students to think creatively and come up with innovative solutions to engineering problems.
- **Design Freedom**: It allows for the creation of complex geometries and custom designs that would be difficult or impossible with traditional manufacturing methods.

(iv) **Collaboration**:
- **Team Projects**: 3D printing projects often require teamwork, fostering collaboration and communication skills among students.
- **Peer Learning**: Students can learn from each other's approaches and techniques, enhancing the overall learning experience.

(v) **Rapid Prototyping**:

Quick Iteration: Students can quickly produce prototypes, test them, and
- make necessary adjustments, speeding up the design and development process.
- **Immediate Feedback**: Rapid prototyping allows for immediate feedback and iterative improvements, which is crucial for learning and innovation.

(vi) **Cost Efficiency**:
- **Reduced Material Waste**: 3D printing typically uses only the material needed for the part, reducing waste and lowering material costs.
- **Affordable Prototyping**: It provides a cost-effective way to create prototypes and models compared to traditional manufacturing methods.

(vii) **Versatility**:
- **Cross-Disciplinary Applications**: 3D printing can be used in various engineering disciplines, from mechanical and electrical to civil and biomedical engineering.
- **Wide Range of Materials**: It supports a variety of materials, including plastics, metals, and composites, making it adaptable to different projects and requirements.

(viii) **Real-World Application**:
- **Industry Relevance**: Familiarity with 3D printing prepares students for the demands of modern engineering industries, where additive manufacturing is increasingly prevalent.
- **Digital Transformation**: It equips students with the skills needed to adapt to and thrive in a digitally transformed engineering landscape.

Examples of 3D Printing applications in civil, electrical, and mechanical engineering disciplines are explained in 3.1 to 3.3 respectively.

3.1 Civil Engineering

Graphical representation of projects is a crucial skill for Civil Engineering students. However, poor teaching methods, outdated approaches, and a lack of hands-on experiments often deter students from pursuing STEM disciplines. Integrating 3D design technology into higher education can significantly enhance student engagement and improve the quality of learning. This modern approach provides interactive and practical experiences, making complex concepts more accessible and stimulating interest in STEM fields (Gonçalves and Santos, 2019)

3D devices are pushing construction towards automation: reducing labour and increasing safety, reducing construction time on site and production costs (Lotfi and Sameh, 2020). The advent of 3D technology has introduced innovative methods for effectively communicating engineers' ideas. It provides clear instructions on construction processes and offers a visual preview of how projects will appear upon completion. This enhances understanding and collaboration, making it easier to convey complex designs and concepts. This accessibility allows educators to integrate 3D technology into their curricula, enhancing the learning experience for students (Gonçalves and Santos, 2019). Figure 2 depicts a 400-square-foot house constructed from the ground up in just 24 hours in Moscow by a Russian company. The entire building process was completed on site using a mobile 3D printer (Mehmet and Yusuf, 2017).

Figure 3; (a) Front view of Apis Cor House (b) Contour Crafting Process Apis Cor House

3.2 Electrical Engineering

The development of 3D models is currently advancing in the field of electrical engineering education. Consequently, it is essential for higher education instructors and students to utilize 3D models of electrical engineering equipment for effective laboratory work, which will also be crucial for their future professional activities (Ilona et al., 2022)

3D technology is indeed crucial in fulfilling key requirements of Industry 4.0. It has demonstrated its capability to manufacture entire electrical machine components, including the winding and stator core, as well as complete rotors with both hard and soft magnetic materials. This advancement not only enhances the efficiency and precision of production processes but also opens up new possibilities for innovation in electrical engineering (Ahmed, Mohamed, and Peter, 2022). Figure 4 shows the 3D-printed hairpin distributed windings prototyped for E-traction motors and skew rotor of induction machine. A waveguide bandpass filter was fabricated using 3D printing technology, it was designed to achieve a Chebyshev bandpass filtering response through coupling matrix theory. This filter is specified to operate at a center frequency of 180 GHz, with a fractional bandwidth of 11% and a return loss of 20 dB across the pass band (Talal, Milan, Yi, Michael, Thomas, and Falko, 2020).

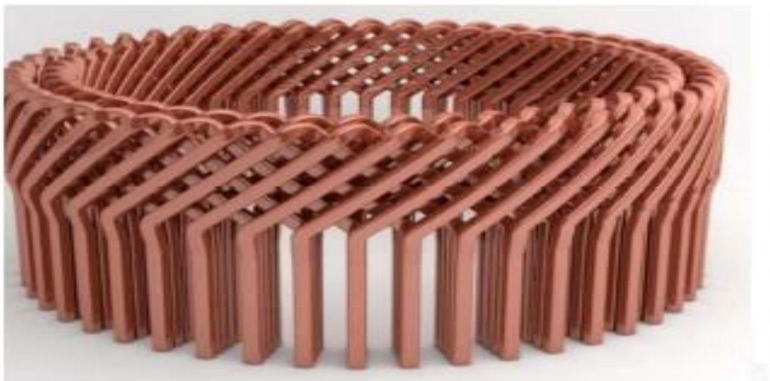

Figure 4: (a)3D-printed hairpin distributed windings for E-traction motors and (b) 3D-printed skewed rotor (Ahmed, Mohamed, and Peter, 2022).

3.3 Mechanical Engineering.

Key elements of undergraduate mechanical engineering education such as modelling and design, manufacturing and testing, materials and equipment are all involves in 3D printing (Jingyu, Noah, Blake, James, and Yingtao, 2019). Incorporating 3D modeling into education will significantly improve the teaching of mechanical product design and the fabrication of machines and products. It will also foster innovation within our educational system. By using 3D technology, students will be more actively engaged in the learning process, enabling them to design novel and complex engineering structures, better visualize concepts, and gain hands-on experience (Hirpa and Ove, 2021)

Utilizing 3D printing technology allows for the construction of concepts discussed in class, making the learning process more effective and practical. For instance, Figure 5 a, b, and c respectively illustrate the view diagram, 3D CAD model, and 3D printed model of a mechanical component. This hands-on approach enhances understanding and engagement by providing tangible examples of theoretical concepts (Issah, Waleed and Hayder, 2019). By seeing the solid model Students will than seeing three-view diagram.

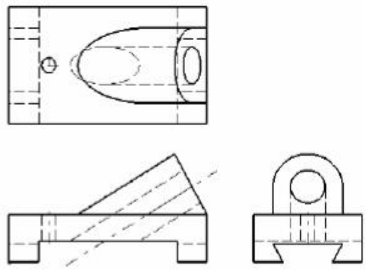
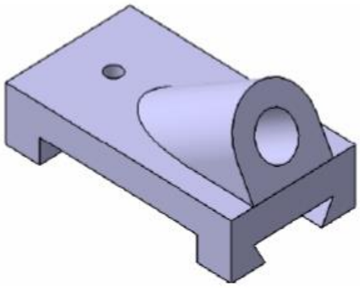
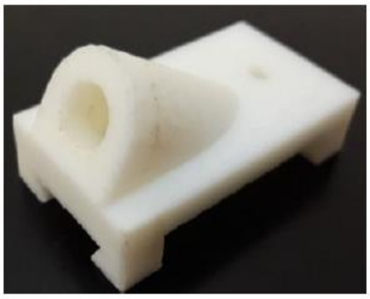

Figure 5; (a) Views diagram, (b) 3D CAD model (c) 3D printed model

4.0 Conclusion

This paper summarized various literatures on the application of 3D printing in engineering education system with emphasis on civil, electrical and mechanical engineering disciplines. The impact of using 3D printing in engineering education is gradually becoming known and therefore, such initiatives is worthy of pursuit.

A better understanding of how to acquire 3D printing skills outside the formal engineering education systems and how it can be integrated is needed. It is surprising that 3D printing is yet to be adopted in many universities and polytechnics engineering and design courses.

Feedback from many industries and various application examples confirms that 3D printers have significant potential as a tool for learning and teaching engineering courses. The ability to radically explore and become familiar with this new trend in technology, innovation and ideas become imperative for engineering students in preparing for effective future working practices. Integration of creative thinking and design process into the curriculum will give the students the opportunity of tackling complex problems that involves deep thinking by experienced engineers. 3D printing enhances product accuracy, foster students' manual techniques and concept and reduces manual processing errors.

Integration of 3D printing in the engineering education curriculum of our higher institutions will enhance both learning and teaching and definitively have a tremendous positive impact on students' and lecturers by creating aiding tools inform of prototype to convert concepts into tangible form in any field of engineering. The finding shows that 3D printing usefulness is enormous for educational institutes, students, researchers as it permits accelerated automation and concoction of more imaginative thought. Relying on literatures and these findings, Ministry of Education, National Board for Technical Education and Nigerian University Commission can design genuine policies for introduction and growing of 3D additive technology into engineering education system.

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