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Original Prusa i3: The Self-Replicating 3D Printer

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Abstract. This is a teaching case inspired by the Czech 3D printer manufacturer Prusa Research, particularly its innovative business model based on self-replication. Born out of RepRap, an open-source project to design self-replicating 3D printers, Prusa Research successfully marketed 3D printers whose plastic parts are 3D-printed. What advantages does 3D printing offer over injection molding? In this case, students first perform cost-modeling exercises to estimate costs of injection molding and 3D printing. They are then guided through a discussion about the advantages of 3D printing. This case may be used as a cost-modeling exercise as well as an advanced Operations Management/Manufacturing case to showcase the relevance of conventional Operational concepts in the context of new manufacturing technologies.

Keywords: 3D printing, additive manufacturing, manufacturing, technology, innovation, entrepreneurship, startup, business model, digitalization, digital operations, open source, open hardware.

1. Prologue

"This is going to be a long flight," thought Logan as the airplane took off from Dallas, Texas for Prague, Czech Republic. An MBA student at the Naveen Jindal School of Management, University of Texas at Dallas and a consultant intern, Logan would report his preliminary analysis and recommendations to Josef Prusa, co-founder and CEO of Prusa Research[1]. The project was about Prusa Research's flagship product, the Prusa i3 3D printer (Exhibit 1). Logan's task was to explore injection molding as a potential replacement manufacturing technology for the plastic parts of the printer. "Injection molding as a *replacement* manufacturing technology?" Logan remembered the confusion as he first read the assignment. "I'm hard-pressed to think of anything plastic that isn't injection-molded." He read on with curiosity as for what the current manufacturing technology was. When Logan finally found out the answer, he gasped in shock and disbelief. The company had been producing plastic parts for the Prusa i3 3D printers—by 3D-printing them on

1. https://www.prusa3d.com

the Prusa i3 3D printers. In other words, the company had produced and sold *self-replicating 3D printers*.

Exhibit 1: The Prusa i3 MK3 3D printer

Logan remembered having to pause and let the idea sink in. As an avid fan of science fiction, he was no stranger to the idea of self-replicating machines. The image of the glowing red eyes in the metal skull of *The Terminator* quickly flashed across his mind and sent a creep down his spine. John von Neumann's universal constructor came next. Logan also remembered reading about NASA's conceptual proposal of a self-replicating space industry. But he never imagined self-replication to rise today as an economically viable mass-manufacturing technology.

After months of research, Logan had learned much about 3D printing, injection molding, and the company he was going to visit. He felt that he had collected enough information needed for the analysis, yet something was still beyond his grasp. "Let me go over everything one more time before landing", thought Logan. He opened up his research notes once again.

2. 3D Printing

Three-dimensional (3D) printing is a process in which a material is joined or solidified layer-upon-layer under computer control to create a three-dimensional object. 3D printing is also known as additive manufacturing to highlight the process of adding layers of the material to form an object, in contrast with subtractive manufacturing processes such as machining where the material is removed from a chunk to form an object. The 3D blueprints for 3D printing are either obtained from scanning physical objects or crafted using computer-aided design (CAD) software. Various technologies have been developed to 3D-print a range of materials including plastics, metals, food or even living cells (to form tissues or organs).

3D printing displays tremendous promises. Its flexibility enables low-cost and rapid prototyping and personalization: artists, designers and engineers can easily materialize their digital blueprints during iterative experiments and improvements, and doctors and apparel makers can make implants, prosthetics and clothes that perfectly fit each patient or customer. In addition, the technology is also used in scenarios where traditional manufacturing technologies are ineffective. For example, General Electric (GE)'s aviation department 3D-prints turbine blades in titanium aluminide (TiAl) for the GE9X jet engine powering Boeing's next-generation 777X jets[2] (Exhibit 2). TiAl is a strong, heat-resistant and light material ideal for turbine blades, but it cannot be machined due to its brittle quality, and molding the material is also difficult and expensive. 3D printing proves to be the most effective manufacturing technology for TiAl. Finally, 3D printing is quickly gaining ground in the construction industry as a cost-effective, versatile, fast and less wasteful construction method[3]. However, where alternative mass-manufacturing technologies such as injection molding and casting are viable, 3D printing has typically not taken over.

2. https://www.ge.com/reports/future-manufacturing-take-look-inside-factory-3d-printing-jet-engine-parts/
3. https://www.cnn.com/2021/03/18/business/california-3d-printed-neighborhood-trnd/index.html

Exhibit 2: GE's 3D-printed turbine blades

3. SLA, SLS, and FDM

Plastics are the earliest and by far the most popular material for 3D printing. In 1981, Hideo Kodama of Nagoya Municipal Industrial Research Institute invented two additive methods for fabricating three-dimensional plastic models with photo-hardening thermoset polymer, whereby the liquid resin is solidified by ultraviolet (UV) exposure, and the exposure area is controlled by either a mask patter or a scanning fiber transmitter[4]. Based on this principle, Charles Hull built the world's first 3D printer in 1984 and filed the patent for stereolithography (SLA)[5]. Because the technology involves liquid resin, the printing and post-processing (rinsing, curing and drying) can be messy. The need for a full tank of resin tends to limit the maximum printable size. Objects printed with SLA have a translucent appearance, which is a unique feature but can also be a limitation when a solid appearance is preferred. Compared with FDM, a key advantage of SLA is its printing resolution and accuracy; the light-based technology can materialize fine details at the 0.01mm level. Therefore, SLA is most suitable for accurate prototyping and miniature model printing.

Around the same time when SLA was invented, Carl Deckard and Joe Beaman at the University of Texas at Austin developed and patented another 3D-printing technology called selective laser sintering (SLS)[6], whereby

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4. Hideo Kodama, "Automatic method for fabricating a three-dimensional plastic model with photo-hardening polymer," *Review of Scientific Instruments*, Vol. 52, No. 11, pp. 1770-73, November 1981.
5. Charles W. Hull, U.S. Patent 4,575,330, 1981.
6. Carl R. Deckard, U.S. Patent 4,863,538, 1986.