# Transforming a Rapid Prototyping Course to an Additive Manufacturing Course

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***Abstract***

*The additive manufacturing industry continues to evolve with the advent of new and different materials and machines and the implementation of Industry 4.0. The transformation of a technology program's rapid prototyping course to an additive manufacturing course occurred recently. The technology program also adopted Industry 4.0 as a framework for all its degree program and is developing an advanced manufacturing lab. The role and history of the course and its associated lab, its evolutionary history of the laboratory component as it relates to instruction and planning for additional additive manufacturing laboratory capacity is discussed. The addition of metal 3D printers to supplement current capabilities in plastic printing is also discussed.*

**Introduction and Background**

Engineering and technology programs realize the benefits of additive manufacturing course. Bernard, Thompson, Moroni, Vaneker, Pei, and Barlier (2019) suggest that "Additive Manufacturing (AM) enables designers to consider the benefits of digital manufacturing from the early stages of design". Sheladiya and Sheladiya (2019) suggest that additive manufacturing is considered vital to the Industry 4.0 movement. They remarked that "In the current era, the use of modern skills of Additive Manufacturing within the context of information technology integration plays a significant role in industrial economic competitiveness". Alabi, Beer, and Wichers (2019) discussed the effect of promotion of additive manufacturing in South African universities. They quoted that "AM research activities within South Africa's universities have shown that it is not too late for developing countries to start and embrace AM technologies both in academia and industry. Based on a SWOT analysis, the prospects of AM technology in South Africa is bright."

This paper presents the migration of a rapid prototyping course to additive manufacture in a technology program. The technology program where the course is housed is also making strides towards adopting an Industry 4.0 framework for its curriculum.

Rapid Prototyping (DESN 3230/3231) course at East Carolina University's Department of Technology System's design program has been taught since spring 2006 and is intended for sophomore or junior students with a background in manufacturing and 3D modeling fundamentals. In 2006, when the course was first deployed, the it focused on prototype building which was the current industrial trend. Fast forward to 2019 (13 years later), the technology has developed into a widely adopted industry practice known as Additive Manufacturing.

The course is a 3-semester hour course and includes 2 contact hours of lecture (DESN 3230) and 2 contact hours of lab (DESN 3231) per week. The course objectives are are listed in Table 1.

| No | Course Objective |
|---|---|
| 1 | Understand the history, important development and application of rapid prototyping. |
| 2 | Develop a basic understanding of the Principles of Rapid Prototyping (RP). |
| 3 | Develop a basic understanding of Liquid based RP systems. |
| 4 | Develop a basic understanding of Solid and Powder based RP System. |
| 5 | Develop a basic understanding of materials for Rapid Prototyping. |
| 6 | List the current rapid prototyping technologies available to industry and identify the manufacturer and technology used in each. |
| 7 | Develop a basic understanding of ongoing Research and development in RP Technologies. |
| 8 | Generate suitable STL files capable of producing a part on a rapid prototyping machine. |
| 9 | Produce a prototype part using at least one of the rapid prototyping technologies studied in class. |
| 10 | Identify reverse engineering techniques and list their uses in modern manufacturing. |
| 11 | Identify the role of rapid prototyping service bureaus in modern manufacturing. |

**Table 1. Course objectives of the Rapid Prototyping Course (2006 to present)**

The first machine to be used in the lab was the Stratasys fused deposition modeling (FDM) machine-See Figure 1 (a). The machine was as put out of service in 2014. The second 3D printing machine which was bought and used by the lab was a powder 3D printing Z Corp 310 machine in 2007-See Figure 1 (b). This machine was used for roughly nine years and then donated to the university library and put out of service in 2016. The third machine that was a Z Corp color 650 machine which was bought in 2010 and put out of service is 2019- See Figure 1 (c). The fourth machine which is a Stratays SST FDM machine was bought in 2014 and is being currently used- See Figure 2.

a) 2006-2014 b) 2007-2014 c) 2010-2019

**Figure 1: Historical usage of the 3D printing Machines in the Rapid Prototyping Course**

**Figure 2. Stratasys dimension FDM SST machine (used from 2014 to current).**

The course currently uses the FDM SST machines and the capabilities in the academic library. In conjunction with the library's staff, the authors played a key role in installing rapid prototyping capabilities which the students of the course currently use (Zuberbier, Agarwala, Chin, Sanders ;2016, 2017).


**Figure 3. Rapid Prototyping Capabilities in the Library (used currently).**

**Implementation**

The department housing the course is investing considerable resources advanced machining and robotics, Industry 4.0, additive manufacturing, and warehousing technologies to better prepare our students to be more successful and competitive in today's industry. The lab environment will provide a fully integrated environment that combines Information Technology (IT) with Operations Technologies (OT) to provide our students with unparalleled skill sets that will make them highly competitive and sought after by business & industry. The advanced manufacturing lab establishment is depicted in in Figure 4. Phase 3 (circled region) is the phase where equipment pertaining to additive manufacturing and metal 3D printing is planned.

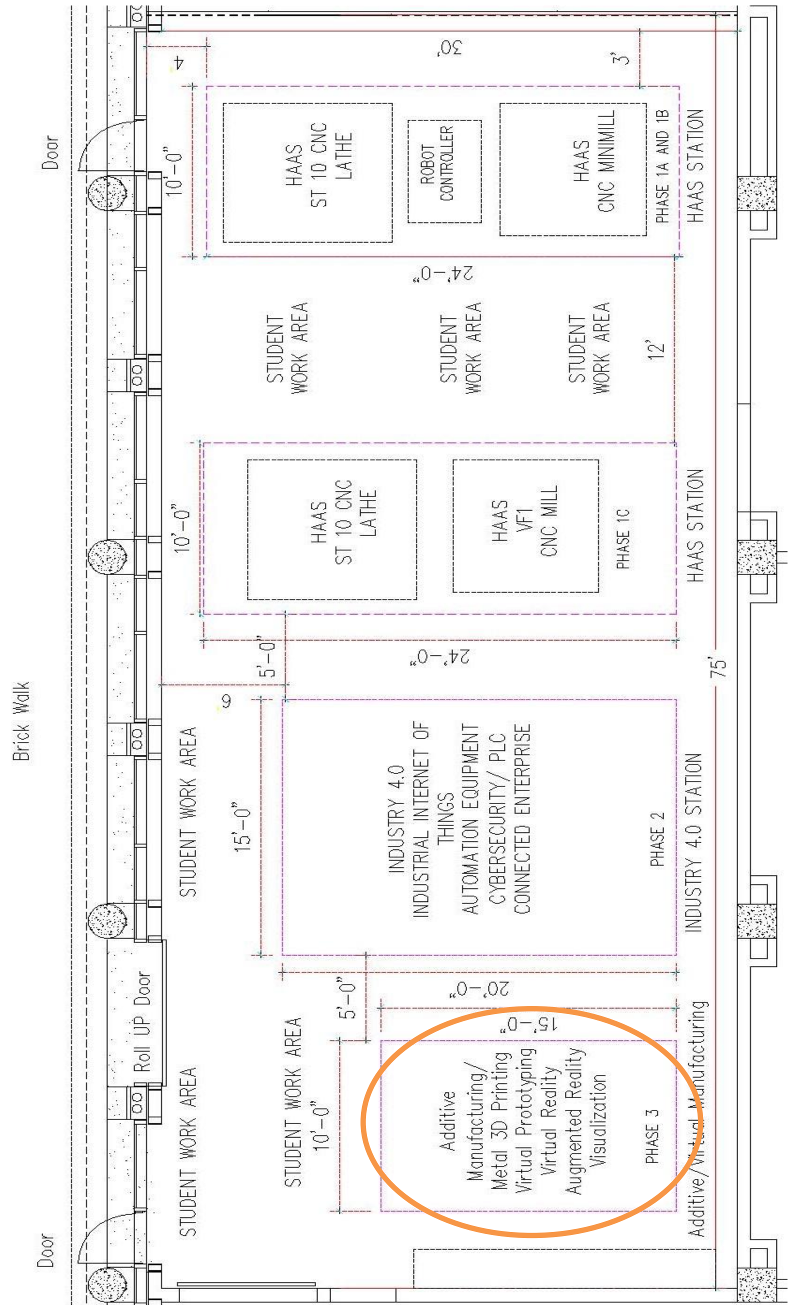


**Figure 4. Advanced manufacturing lab establishment.**

The environment will allow students to use current technology to learn everything from Product sourcing/procurement to consumption and everything in between, including, but not limited to:

- Production planning and manufacturing using advanced tools including computer and virtual reality simulations
- Advanced Manufacturing processes and Additive Manufacturing
- Industrial Computer Networks and Cybersecurity
- Automatic Identification and Data Capture (AIDC) technologies to accurately identify and track products
- Enterprise Resource Planning such as (SAP) and/or Manufacturing Execution Systems (MES)
- Warehousing, including autonomous systems, including those used in automated storage and retrieval environments
- Inventory management, fully integrated with the AIDC and ERP/MES systems
- Transportation logistics, including appropriate tracking and security technologies

**Course Transformation and Development**

To align the rapid prototyping course with the program initiatives, plans are currently underway to rename the DESN 3230 course from Rapid Prototyping to Additive Manufacturing and DESN 3231 to Additive Manufacturing Lab. The objectives of the transformed course are listed in Table 2.

| No | Objective |
|---|---|
| 1 | Understand the history, important developments, benefits, and applications of additive manufacturing. |
| 2 | Develop a basic understanding of the principles of additive manufacturing, additive manufacturing process chain, file formats, and work flow. |
| 3 | Develop an understanding of different materials used in additive manufacturing such as polymers, metals, composites etc. |
| 4 | Develop an understanding of the operation of latest additive manufacturing technologies. |
| 5 | Understand the applications of additive manufacturing technologies in various sectors of the industry. |
| 6 | Develop an understanding of how to design for additive manufacturing. |
| 7 | Develop a basic understanding of ongoing research and development in additive manufacturing. |
| 8 | Develop an understanding of additive manufacturing in context of Industry 4.0. |
| 9 | Develop an understanding of direct metal additive manufacturing and various technologies of direct metal additive manufacturing |

**Table 2. Planned Additive Manufacturing Course Objectives**

Three additive manufacturing machines are currently under consideration for the planned additive manufacturing lab component. The first metal printer considered is a Marked Forged Metal X 3D printer as depicted in Figure 5. Selected specifications of the 3D printer are provided in Table 3.

**Figure 5. MarkedForged Metal X 3D printer. Courtesy MarkedForged**

| Specification Type | Specification |
|---|---|
| Build Volume | 300 mm x 220 mm x 180 mm |
| Resolution | 50 µm |
| Material | 17-4 Stainless Steel, 316L Stainless Steel, INCONEL, IN Alloy 625B, Tool Steel, H13 Tool Steel, A-2 Tool Steel, D-2 Tool Steel |
| Material Type | Media cartridge-Bound powder |
| Price Range | $124,990.00 |
| Process | Atomic diffusion additive manufacturing. |

**Table 3. MarkedForged Metal X 3D printer specifications. Courtesy MarkedForged**

The second 3D printer considered is a Desktop metal 3D printer as depicted in Figure 6. Selected specifications of the 3D printer are listed in Table 4.

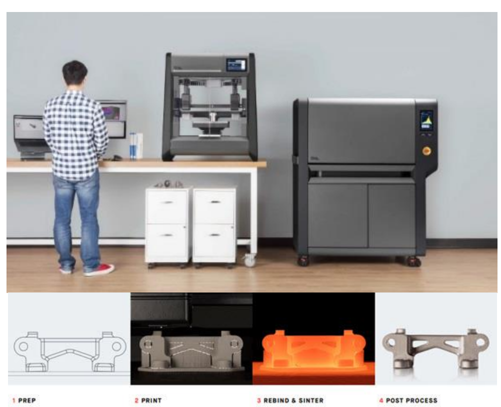


**Figure 6. Desktop Metal 3D printer. Courtesy Desktop Metal**

| Specification Type | Specification |
|---|---|
| Build Volume | 305 mm x 205 mm x 205 mm |
| Resolution | 50 µm |
| Material | 17-4 stainless steel, 316L stainless steel, Alloy 625, H13 tool steel, AISI 4140, Copper |
| Material Type | Hot swappable DM cartridges |
| Price Range | $177,316 |
| Process | Bound Metal Deposition |

**Table 4. Desktop Metal 3D printer specifications. Courtesy Desktop Metal**

The third printer under consideration is General Electric (GE) concept laser Mlab cusing R 100w as depicted in Figure 7. Selected specifications of the 3D printer are listed in Table 5.


**Figure 7. GE concept laser Mlab cusing R 100w. Courtesy GE Additive**

| Specification Type | Specification |
|---|---|
| Build Volume | 90 mm x 90 mm x 80 mm |
| Resolution | 30 µm |
| Material | GE Additive 316L, Remanium star® CL, Rematitan® CL, GE Additive 17-4 PH, AP&C Ti64 grade 23 CL, AP&C CpTi grade 2 CL, Parameters Available, Bronze, Silver 930, Gold, Yellow, Gold, Rose Platinum, AlSi10Mg |
| Material Type | Powder Metal |
| Price Range | $280,448.00 |
| Process | Direct Metal Laser Melting |

**Table 5. GE concept laser Mlab cusing R 100w. Courtesy GE Additive**

## Discussion

We started offering the course in Spring 2006. At that time the technology taught in the class focused on prototype building which was the current industrial trend. Fast forward to 2019 (13 years later), the technology has developed into a widely adopted industry practice known as Additive Manufacturing.

Many engineering and technology programs face challenges in teaching additive manufacturing materials and machines are changing continuously. According to the current trend, students with know-how in metal printing have a career edge when compared to students who just acquire skills in polymer printing such as ABS and PLA (Steele, 2017). Increasingly institutions are considering 3D metal printers (Weiss, 2019).

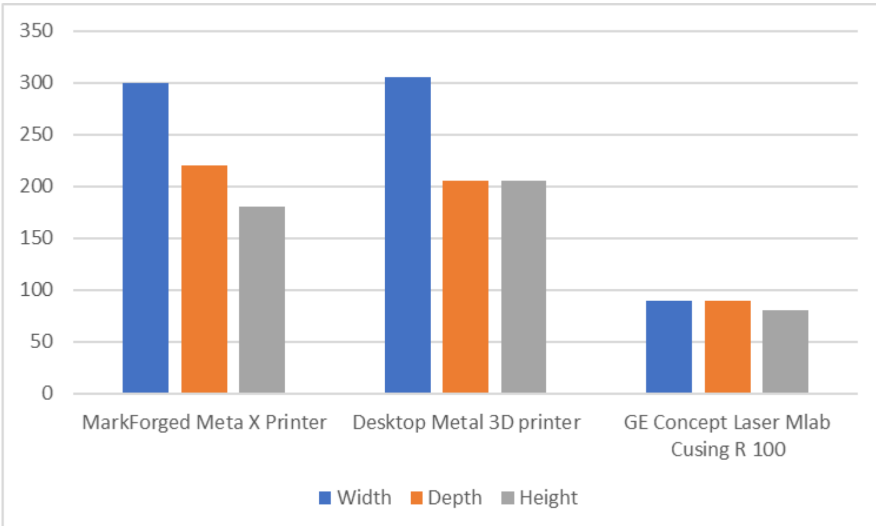


**Figure 8. Build volumes of three metal printers under consideration**

Figure 8 depicts the build volume of the three metal printers under consideration. The build volume of MarkForged Metal X and Desktop Metal Printers are almost identical, and both are considerably larger than GE concept laser Mlab Cusing R100.

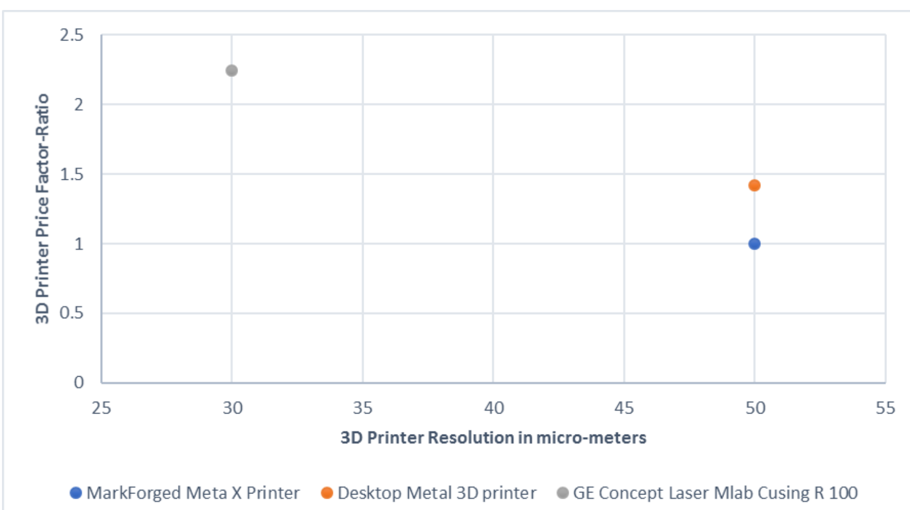


**Figure 9. Resolution of three metal printers under consideration**

Figure 9 depicts the price factor versus resolution of the three metal printers under consideration. The price of the MarkForged Metal X printer is treated as one and the price of the remaining 3D printers are expressed as a ratio. The information regarding the cost of the machines have been obtained from the companies and is confidential information. The resolution of MarkForged Metal X and Desktop Metal Printers are almost identical. The resolution of GE concept laser Mlab Cusing R100 is better than both printers. The price factor of MarkForged Metal X is set two 1. The price of Desktop Metal Printers is almost one and half times the price of MarkForged Metal X printer. The price of GE concept laser Mlab Cusing R 100 is almost two and a half times that of MarkForged Metal X printer.

## Conclusions

This paper presents the transformation of a rapid prototyping course to an additive manufacture course in a technology program. The technology program where the course is housed is also making strides towards adopting an Industry 4.0 framework for its curriculum. We started offering the course in Spring 2006. At that time the technology taught in the class focused on prototype building which was the current industrial trend. Fast forward to 2019 (13 years later), the technology has developed into a widely adopted industry practice known as Additive Manufacturing. The course is currently developing course objectives and upgrading its lab capabilities in additive manufacturing to supplement with 3D Metal printers. The Program is currently evaluating three metal printers and the results of the evaluations are summarized. The initial discussions with the industry partners and the literature on the current trends suggests that although filament infused metal printing such as Metal X and Direct Metal have a larger build volume, are less hazardous, and are less expensive than laser sintered technologies such a GE concept laser, students with knowledge in laser sintered additive manufacturing have better career prospects.

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