

# Chapter 16

## Complexity Analysis in Additive Manufacturing for the Production of Tissue Engineering Constructs

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### ABSTRACT

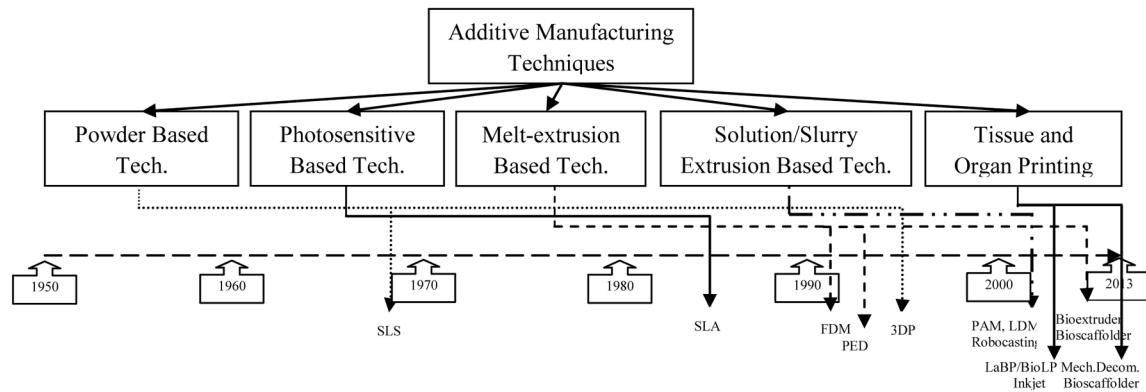
*Additive Manufacturing (AM) is a process of making a Three-Dimensional (3D) solid object of virtually any shape from a digital model that is used for both prototyping and distributed manufacturing with applications in many fields, such as dental and medical industries and biotech (human tissue replacement). AM refers to technologies that create objects through a sequential layering process. AM processes have several primary areas of complexity that may not be measured precisely, due to uncertain situations. Therefore, this chapter reports an analytical model for evaluating process complexity that takes into account uncertain situations and additive manufacturing process technologies. The model is able to rank AM processes based on their relative complexities. An illustrative example for several processes is demonstrated in order to present the application of the model.*

### 1. INTRODUCTION

The fabrication of micro- and nano-structured biodegradable constructs for tissue engineering (TE) is dependent upon the development of techniques and methodologies. Many techniques have been developed for the production of TE such as additive manufacturing (AM). AM is suitable for TE constructs with complex shapes and microstructure because it has a high level of automation and accuracy. In literature pertaining to AM technologies (powder-based and photosensitive-based techniques), four categories have been introduced (Hutmacher et al., 2004):

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*Figure 1. Chronological taxonomy of the AM techniques*



1. stereolithography (SLA)
2. selective laser sintering (SLS)
3. three-dimensional printing (3DP)
4. fused deposition modelling (FDM)

SLA, which is based on laser or ultraviolet (UV) light, is an AM technique that selectively polymerizes layers of a photosensitive polymer. In 1989, selective laser sintering (SLS), which is based on the selective sintering of a polymer, ceramic, or hybrid powder bed, and high-intensity laser beam, was developed by Deckard (1989). Later, another powder-based technology called three-dimensional printing (3DP) was developed that was based on the controlled deposition of a binder material laid on a powder layer using an inkjet head. Since these techniques were not suitable for the rapid manufacturing of prototypes for industry, Crump (1992) proposed a fused deposition modelling (FDM) technique, which was an extrusion of a polymeric filament through a heated nozzle. As an extension, precision extrusion deposition (PED), which was a melt-extrusion AM technique, was introduced. This technique was based on a screw extruder, enabling the processing of polymer pellets for the controlled deposition of a melt filament. In conjunction with melt-extrusion-based technology, Vozzi et al. (2003) studied the micropositioning system with a pressure-activated microsyringe that was well-known as a pressure-assisted microsyringe (PAM). Conversely, low-temperature deposition manufacturing (LDM) was used to exploit a controlled cooling chamber. Xiong et al. (2002) mentioned that LDM allows the deposition process of a polymeric slurry to operate at low temperatures. Finally, the fourth category is the tissue and organ printing technologies such as Laser-assisted BioPrinting (LaBP), and Biological laser printing (BioLP™). As an efficient replacement for a cartridge-based system, the LaBP techniques were introduced by Koch et al. (2012). Also, to print a variety of cell types, Biological laser printing (BioLP™) was developed. Figure 1 shows the chronological taxonomy of the AM techniques.

Complexity of an AM process can be defined through two major aspects: technical design and processes. However, these aspects of the AM technique entail a lot of information that may not be measured precisely because of uncertain situations (Pich et al., 2002; Shafiei-Monfared & Jenab, 2011a/b). As a result, AM project failures are numerous in practice (Tatikonda & Rosenthal, 2000). In other studies, the authors suggest that uncertainty required adapting a management style to the process uncertainty profile, as measured by the dimensions of process size, product structure, and experience with the technology

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