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Product-Service Systems across Life Cycle

# Additive Manufacturing applications in the domain of Product Service System: an empirical overview

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**Abstract**

This paper is a focus study to introduce an alternative approach to the existing ones, which could be taken to implement Additive Manufacturing (AM) systems for industrial applications. This approach is mainly based on the use of Product Service Systems (PSS) concept in order to turn AM into a more relevant field for service-based purposes within industrial applications. To do so, an AM profile, which is characterized with the similar notions forming the conceptual basis of PSS is detailed, and then the profile is framed for the new service oriented approach to highlight AM's competences in this field. Having found the interconnecting links between these two concepts, the intended approach for implementation would then be discussed and further developed in more detail to include the best use cases of the previous AM case studies as a guide on how to exploit AM's capabilities in similar ways, only modified for a given industrial business which is based on service development. The use cases would also introduce a few of the most successful examples in the production-service systems which have already taken advantage of three-dimensional printing (3D printing) which is one the subcategories of AM in lower tier (desktop) applications. These customer scale applications of 3D printing alongside portfolio analysis of AM in the field of industrial services could shed light for implementing further service-centric research in the advanced manufacturing systems.



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*Keywords:* Additive Manufacturing; 3D Printing; Product Service Systems; Spare parts; Case studies

## 1. Introduction

Manufacturers and researchers have been trying to adapt Additive Manufacturing (AM) within a broad range of industries, while trying to find the most suitable configurations and trade-offs of the production line technologies, logistics and supply chain capacities alongside business objectives so as to maximize the benefits resulting from AM's implementation. Although AM has been successfully proved to be a feasible alternative for traditional mass manufacturing techniques in several industrial cases, its practical applications have been mainly affiliated with rapid prototyping and modeling practices. This is an ongoing trend, which is being actively followed by manufacturers and suppliers, researchers and governments all over the world in order to increase AM's competitiveness and promote it in more actual production levels. These levels include manufacturing practices ranging from consumer goods production to the spare parts supply chain configurations. Aside from industrial level implementations, and moving on towards a more final customer scale, AM has been more competitive compared with other alternatives in some particular aspects. AM consists of several technologies, and can be described following the ASTM definition [1]: "The additive manufacturing is a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies". Referring to ASTM classification, it is possible to group these different techniques in seven categories, each characterized by a different product building process: Binder jetting, Directed energy deposition, Material extrusion, Material jetting, Powder bed fusion, Sheet lamination and Vat photo-polymerization. In the next sections, explaining the main impacts of Additive manufacturing upon PSS domain, all these technologies will be considered.

Although desktop 3D printing technological variation has



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been one of the most interesting fields of application for lower tier applications, and despite the fact that enabling the concept of PSS has been proved to work with high rates of success for this technological subset in multiple nonindustrial examples, contents of this text have been setup to address the potential areas which can be considered for industrial applications. Thus, it seems reasonable to investigate potentials of PSS for a broader category and make the case for the AM system rather than focusing on one of its subcategories. The specific aspects of AM which are of particular importance from a service-based point of view are sustainability, environmental impacts, economic competitiveness, resource and energy efficiency, digital based infrastructure as well as the overall quality of the process both regarding the manufacturing processes and the final products. These aspects are the main building blocks of this study to further diffuse AM system into the service business sector, and indirectly correspond the research with standards and regulations that exist in sustainability and environmental subjects.

In the following, a brief introduction of all these aspects, which have the potential to get promoted via the concept of PSS and be used in an industrial service development business, are presented. Following their introductions, some of the best practices whose main source of competitiveness are derived from AM technologies are presented to build a functional link to certain PSS concepts.

## 2. AM Competitiveness in the Service Area

AM as a manufacturing system has already been well defined in the literature [13], and while some of its most concerning aspects have been thoroughly studied through case studies [4] by researchers to identify the possible trade-offs between AM and Traditional Manufacturing (TM), there are some particular aspects of AM which are of more importance in the field of service development area. These aspects theoretically have the potential to define the ways in which AM could be exploited to the most to increase its positive impacts over the performance of a given company which is active in the service development area to serve its customers, rather than product development. This notion is believed to be derived from AM's successful case implementations in the fields of spare parts supply chain [11] and customized parts. Putting aside the benefits realized to manufacturers as a result of AM adoption for not being the focus of this study, the advantages extend well beyond cost effectiveness of small volume manufacturing, and go further to include the factors which are mutually important for all the actors involved in the value chain, especially service developers and their customers. These advantages could provide multiple leverages over the use of AM within New Service Development (NSD) practices. The potential list of AM leverages which result from its characteristics and could be linked to the PSS concept can be categorized into two major fields of environmental and economic benefits; out which, certain key performance indicators can be extracted for the service sector. The indicators provide important information about their specific roles towards improvement of sustainability, introduction of advantages that could be resulted out of their considerations, identification of the ways that they can be implemented, and finally the extent to which various entities of any given PSS can be related to them. These two major fields are discussed in detail in the following paragraphs.

### *2.1. Environmental Leverages*

The environmental leverages are one of the most important broad aspects to be considered while studying roles of PSS in a society. In one of the documents drafted by the United Nations Environment Program [25], the PSS is identified as a comprehensive solution which can be used to resolve sustainability concerns of a society, by providing and promoting patterns of production and consumption towards governments, companies and citizens. The importance of environmental concerns with respect to all stakeholders has been highlighted in all over the document. The most impactful aspects of AM in terms of environmental factors which could contribute to the improvement of sustainability are its capabilities to shorten the supply chain by cutting long distances of transportation and eliminating unnecessary actors [13], significant reduction of raw materials consumption and boosting their efficient usage [18], as well as reduction of the carbon footprints [7].

The fact that AM's requirements are only the CAD data and raw materials to be loaded onto the machine have significant implications on the length and level of simplicity of the supply chain. By getting closer to customers and the enhanced ability of the AM machines to produce the products in one part [26], contrary to the TM machines which require multiple assemblies to be performed on the ready parts, both the length and communications complexities which are always present in TM supply chains are resolved. Localization of production and increasing level of decentralized production are directly resulted out of AM systems [14]. Also, production of the products in single part eliminates the need for costly inventory controls in several warehouses and the corresponding transportations and logistics to get them to the point of use [12, 17].

Material efficiency is yet another interesting aspect of AM systems which could provide several opportunities in order to save costs and reduce negative environmental impacts. The layer by layer manufacturing of the parts makes it possible for the producers to consume raw materials only for the required level of production [3, 8], while the ability to recollect the unused powder in the build chamber [16] would further increase savings on the raw materials consumption. Although reusing the powder depends on the process and its impact over the molecular structure, this is a potential area of research that can have effective results on the overall costs of the process.

### *2.2. Economic Leverages*

Another major field that can contain certain economic performance indicators on AM implementation in the service area is the set of economic leverages. The performance indicators that can be extracted out of this field mainly address the financial benefits that can be gained in the PSS processes as a result of AM implementation. The product