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Cloud-based design and manufacturing: A new paradigm in digital manufacturing and design innovation

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HIGHLIGHTS

- We present a new paradigm in digital manufacturing and design innovation, namely cloud-based design and manufacturing (CBDM).
- We identify the common key characteristics of CBDM.
- We define a requirement checklist that any idealized CBDM system should satisfy.
- We compare CBDM with other relevant but more traditional collaborative design and distributed manufacturing systems.
- We describe an idealized CBDM application example scenario.

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ABSTRACT

Cloud-based design manufacturing (CBDM) refers to a service-oriented networked product development model in which service consumers are enabled to configure, select, and utilize customized product realization resources and services ranging from computer-aided engineering software to reconfigurable manufacturing systems. An ongoing debate on CBDM in the research community revolves around several aspects such as definitions, key characteristics, computing architectures, communication and collaboration processes, crowdsourcing processes, information and communication infrastructure, programming models, data storage, and new business models pertaining to CBDM. One question, in particular, has often been raised: is cloud-based design and manufacturing actually a new paradigm, or is it just "old wine in new bottles"? To answer this question, we discuss and compare the existing definitions for CBDM, identify the essential characteristics of CBDM, define a systematic requirements checklist that an idealized CBDM system should satisfy, and compare CBDM to other relevant but more traditional collaborative design and distributed manufacturing systems such as web- and agent-based design and manufacturing systems. To justify the conclusion that CBDM can be considered as a new paradigm that is anticipated to drive digital manufacturing and design innovation, we present the development of a smart delivery drone as an idealized CBDM example scenario and propose a corresponding CBDM system architecture that incorporates CBDM-based design processes, integrated manufacturing services, information and supply chain management in a holistic sense.

1. Introduction

In its initial application field of information technology (IT), cloud computing has proven to be a disruptive technology. It leverages existing technologies such as utility computing, parallel computing, and virtualization [1]. Some of its key characteristics include agility, scalability and elasticity, on-demand computing, and self-service provisioning [2]. Adapted from the original cloud computing paradigm and introduced into the realm of computer-aided product development, cloud-based design and manufacturing (CBDM) is gaining significant momentum and attention from both academia and industry. Cloud-based design and manufacturing (CBDM) refers to a service-oriented networked product development model in which service consumers are enabled to configure, select, and utilize customized product realization resources and services ranging from CAE software

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Table 1
Cloud-based manufacturing-related definitions.

Reference	Definition
[13]	"Cloud manufacturing is a computing and service-oriented manufacturing model developed from existing advanced manufacturing models (e.g., application service providers, agile manufacturing, networked manufacturing, manufacturing grids) and enterprise information technologies under the support of cloud computing, the Internet of things (IoT), virtualization and service-oriented technologies, and advanced computing technologies".
[14]	"Cloud manufacturing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable manufacturing resources (e.g., manufacturing software tools, manufacturing equipment, and manufacturing capabilities) that can be rapidly provisioned and released with minimal management effort or service provider interaction".

to reconfigurable manufacturing systems. This is accomplished through a synergetic integration of the four key cloud computing service models: Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS), Hardware-as-a-Service (HaaS), and Software-as-a-Service (SaaS) [3]. In order to fully grasp the breadth, depth, and opportunities of CBDM as an emerging paradigm for distributed and collaborative product development [4–6], it is advisable to discuss its two counterparts: cloud-based design (CBD) and cloud-based manufacturing (CBM) separately before shedding more light on how they may act in concert.

Cloud-Based Design (CBD) refers to a networked design model that leverages cloud computing, service-oriented architecture (SOA), Web 2.0 (e.g., social network sites), and semantic web technologies to support cloud-based engineering design services in distributed and collaborative environments [7,4]. Some of the important requirements of a CBD system include (1) it must be cloud computing-based; (2) it must be ubiquitously assessable from mobile devices; and (3) it must be able to manage complex information flow. A detailed requirements checklist for developing CBD systems will be discussed in Section 3. While an ideal CBD system does not yet exist, some companies already develop and provide select critical components for CBD systems. For instance, Autodesk offers a cloud-based platform, Autodesk 123D [8], which allows users to convert photos of artifacts into 3D models, create or edit the 3D models, and generate associated prototypes with remote 3D printers accessed through the Internet. In addition, Autodesk offers a cloud-based mobile application, AutoCAD 360 [9], which allows design engineers to view, edit, and share AutoCAD digital files using mobile devices such as smartphones or tablets. 100kgarages.com [10], a social network site for connecting consumers with small and medium-sized design companies or individual design engineers, allows a service consumer to search for capable and qualified design service providers in a virtual community by providing consumers with each alternative service provider's profile page. Each profile page includes information such as specialties and sample designs of a service provider.

Cloud-Based Manufacturing (CBM) refers to a networked manufacturing model that exploits on-demand access to a shared collection of diversified and distributed manufacturing resources to form temporary, reconfigurable production lines which enhance efficiency, reduce product lifecycle costs, and allow for optimal resource allocation in response to variable-demand customer generated tasking [11,12]. Table 1 presents another two widely used definitions of CBM. Although each definition may focus on a unique aspect of CBM, they include common elements such as networked manufacturing, ubiquitous access, multi-tenancy and virtualization, big data and the IoT, everything-as-a-service (e.g., infrastructure-as-a-service, platform-as-a-service, hardware-as-a-service, and software-as-a-service), scalability, and resource pooling.

Like in the CBD case discussed before, an ideal, fully developed CBM system does not yet exist. Again, a number of companies have started to develop and provide select components for CBM systems. For example, Quickparts [15] is a cloud-based sourcing platform with a focus on low-volume production for custom manufactured rapid prototypes. Quickparts connects service consumers to providers through an instant quoting engine, which transformed sourcing processes from manual to real-time and automatic. Quickparts enables users to upload their CAD data from a variety of commercial CAD software packages such as CATIA and SolidWorks. Based on geometric analysis, Quickparts instantly generates a list of qualified service providers who can manufacture these digital models. Another cloud-based sourcing platform with a focus on high-volume production, LiveSource [16], developed by MFG.com, allows service consumers to have access to request for quotations being sourced by more than 200,000 global service providers. LiveSource enables service consumers to discover and collaborate with quality service providers at shorter deliver times, reduced costs, and a more flexible supply chain. In addition to the two cloud-based sourcing platforms, 3D Hubs [17], a web-based 3D printing platform, helps connect 3D printing service consumers with providers in the local area. According to 3D Hubs, most 3D printer owners use their devices on average less than 10 h per week. The goal of 3D Hubs is to allow 3D printer owners establish social connections within their local 3D printing community to increase the utilization of their devices. 3D Hubs has established an innovative business model that creates and delivers value to both 3D printing service consumers and providers. First, each hub, i.e., a 3D printing service provider, decides how much they will charge to 3D print an item. Second, 3D Hubs examines whether a 3D model is watertight using a cloud-based geometric analysis tool [18], conducts printability analysis to verify whether the 3D model is printable, and automatically repair the 3D model if necessary. Third, once the 3D model passes inspection, it will be 3D printed by the hub. 3D Hubs adds a fifteen percent on top of the original quote.

As stated before, CBDM is a decentralized and networked design and manufacturing model based on many enabling technologies such as cloud computing, social media, the Internet of Things (IoT), and service-oriented architecture (SOA), all of which forms the backbone of this new design and manufacturing paradigm. An ongoing debate on CBDM revolves around several aspects such as definitions, key characteristics, computing architectures, programming models, file systems, operational processes, information and communication models, and new business models pertaining to CBDM. Although a few definitions for CBM have recently been proposed, they are not yet commonly accepted. Moreover, some prototype systems have been developed and are being tested in industry; however, whether or not these prototypes are truly CBDM systems remain a question. Thus, to gain a better understanding of CBDM, a thorough comparison between CBDM and other relevant design and manufacturing systems is required.

The primary objective of this paper is to answer the following question: can cloud-based design and manufacturing (CBDM) be considered a new, emerging paradigm in design innovation and digital manufacturing as we would like to argue, or is it just old wine in new bottles? The secondary research objective is to propose a generic CBDM system architecture that describes how currently existing cloud-based design and manufacturing services can be integrated and what new services and technologies should