A Review on Cloud Manufacturing Technologies of Industry 4.0

Vrund Shah, Jay Vora, Smit Patel, and Rakesh Chaudhari

Abstract The concept of cloud manufacturing was introduced in 2010; however, its significance is getting noticed in recent years. It is being looked at as a new manufacturing paradigm that would help in shifting the approach of the manufacturing industry from being production-oriented to being service-oriented. Although research has been carried out in this field still, there is a lack of understanding of basic concepts, key characteristics, and their relationship with other technologies. In the current study, an attempt has been made to clarify the understanding of the people regarding the aforementioned issues. Also, because its implementation in the industry will be challenging, the key issues and factors influencing its implementation have been discussed in depth.

Keywords Industry 4.0 · Technology · Cloud manufacturing · Cloud computing · User models

1 Introduction

Today's manufacturing enterprises worldwide are getting reshaped and collaboration, innovation, service, and sustainability play a censorious role in that (Li et al. 2011). The manufacturing industry is undergoing a major transformation as it is shifting its approach from being production-oriented to service-oriented (Li et al. 2012). To face the new challenges which are faced due to manufacturing transformation number of information technologies are developing rapidly, such technologies include cloud computing (Armbrust et al. 2010) and the Internet of things (IoT) (Wolf 2009). Owing to the convergence of cloud computing and current manufacturing requirements a new notion of cloud manufacturing is introduced (Li et al. 2010; Ren et al. 2012). It is a new manufacturing paradigm that encourages the growth of a service-oriented, extremely synergistic, and inventive manufacturing base. Cloud manufacturing is a sophisticated, structured manufacturing method aimed at fulfilling growing

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demands for enhanced product personalization, skilled innovations, greater market reaction adaptability, and global collaboration. The capacity to supply consumers with services that support the whole life cycle of a product is cloud manufacturing's biggest strength. This is achieved by giving access to a shared pool in which all manufacturing resources are virtualized. Cloud manufacturing is a convergence of cloud computing, the Internet of things, artificial intelligence, manufacturing technologies, and service computing from a technical standpoint (Li et al. 2011). Although the notion of cloud manufacturing was first suggested in 2010, its importance has just lately been recognized, and rapid progress is being made in both academic study and industrial implementation (Liu et al. 2018; Wu et al. 2012). Even though many researchers from various fields have presented their understanding of cloud manufacturing, there is still a lot of confusion regarding the basic concepts, key characteristics, and their relationship with some related concepts. There is also a need to discuss the key issues related to cloud manufacturing and its future perspective.

The purpose of this study is to address the aforementioned difficulties, and the rest of the paper is organized as follows. The role of cloud computing and other enabling technologies in creating the cloud manufacturing concept was investigated first, followed by the basic concepts of cloud manufacturing. After having determined the user model's basic characteristics, the factors that influence it were investigated. The challenges of putting cloud manufacturing into practice have been researched and documented. Finally, cloud manufacturing's future potential has been discussed.

2 Key Technologies of Cloud Manufacturing

2.1 Fundamental Concepts of Cloud Manufacturing

It is critical to first grasp the essential concepts of cloud manufacturing as a foundation for further discussion.

Manufacturing resource: A manufacturing resource is a unit that supports multiple operations or activities during a product's life cycle. It can be further divided into **hard resources** and **soft resources.** Manufacturing cell or IT hardware can be considered as a hard resource, whereas software, knowledge, data, or other intellectual elements as soft resources (Ren et al. 2013).

Manufacturing capability: It is a metric that is used to assess professional competence. Manufacturing capability can be defined as any manufacturing resources that are required to complete a job during the product life cycle (Ren et al. 2013).

Cloud manufacturing platform or Cloud platform: It manages a networked pool of manufacturing resources as well as capabilities, and an IT-based infrastructure.

Cloud manufacturing service or cloud service: It is a manufacturing capability-based function that aids in the achievement of a goal in a product life cycle activity.

In terms of technology, cloud services are divided into two categories: **On-cloud** and **Off-cloud**. In an On-cloud service, the operator has complete control over the cloud platform, but in an Off-cloud service, the operator must perform additional tasks (Ren et al. 2013).

Cloud user: A person participating in cloud manufacturing can be considered a cloud user (Wu et al. 2012).

Resource visualization: It is a method for mapping a physical manufacturing resource to a logical process.

Capability servitization: It's a method for encapsulating a manufacturing capability into a common cloud service utilizing an abstract description.

Cloud manufacturing system: It is an amalgamation of cloud users, manufacturing resources and capabilities, cloud platform, and certain manufacturing applications (Ren et al. 2013).

2.2 Role of Cloud Computing in Cloud Manufacturing

Cloud computing is defined as a shared computing architecture that meets the needs of external clients by supplying a pool of virtualized, dynamically expandable, managed computing power, storage, platforms, and services through the Internet (Foster et al. 2008). The three basic service modes in cloud computing are infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS) (SaaS) (Buyya et al. 2009). Hardware resources such as computers, networks, virtual machines (VM) which allow the users to modify their own IT infrastructure are provided by IaaS. PaaS provides a platform that allows developers to design, test, and execute their applications. The platforms comprise a programmed execution environment, database, and operating system. Cloud users are given access to and allowed to utilize the application software published on the cloud by SaaS. As users have self-services that are available on-demand cover IT infrastructure, platform, and software using any tablets or smartphones, there is a noteworthy reduction in the investment cost for developing and managing IT systems. This helps fulfill the users' demand for a dynamic computing and storage scale. Key characteristics of cloud computing that contribute to developing the cloud manufacturing concepts are service-centric perspective, virtualization and shared virtual pool of resources, scalability and elasticity, pay-as-you-use scheme, and on-demand customization and user experience.

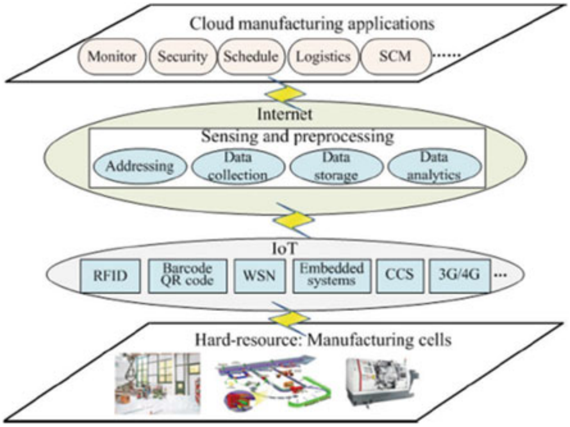


Fig. 1 IoT industrial resource furnace (Gubbi et al. 2013)

2.3 *Key Characteristics of Cloud Manufacturing*

2.3.1 Manufacturing Resources on the Internet of Things and Ever-Present Sensing

Smart communication and sense of production resources are two significant features given by cloud manufacturing. The recent advances of IoT technology which is transforming the Internet play an important role in this (Gubbi et al. 2013). As previously said, manufacturing resources are divided into two categories: hard resources and soft resources. The establishment of integrated Internet of soft resources was easy as compared to hard resources until recent developments in IoT technology. Figure 1 shows a typical IoT industrial resource framework. The invention of technologies like radio frequency identification(RFID) (Buckley 2006), the barcode and quick response (QR) code, and wireless sensor network (WSN) (Akyildiz et al. 2002) which supports the IoT has made the development of a smart network of analogous manufacturing resources specifically the hard resources. To identify the connected resources in the cloud manufacturing environment, each resource has a uniform resource name (URN) (Atzori et al. 2010) and users via looking at the URN-URL (uniform resource locator) table access the URL on the Internet. The smart Internet of industrial "things" will generate a significant amount of "Big Data," necessitating the usage of cloud-based storage technologies (White 2010).

2.3.2 Virtual Manufacturing Society and Demand-Driven Manufacturing System

The research on VM originated the term virtualization (Figueiredo et al. 2005). Virtualization is the process of mapping a genuine physical manufacturing resource to a virtual resource in cloud manufacturing (Ren et al. 2013). It enables the utilization

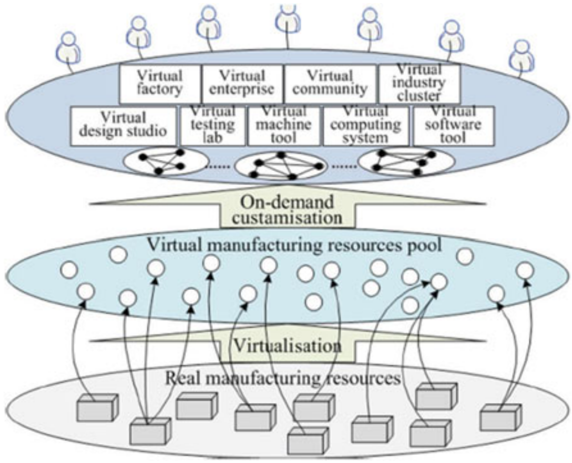


Fig. 2 Virtual manufacturing society (Xu 2012)

and sharing of resources by more users in an optimized manner. Furthermore, because of the flexibility, it possesses it can adapt easily without causing any effect to the service quality. Figure 2 shows a virtual manufacturing society in cloud manufacturing. In manufacturing resource, virtualization mapping plays an important role. Typically there are three types of mapping: one-to-one, one-to-many, and many-to-one (Xu 2012). The real manufacturing resources after virtualization forms a virtual manufacturing resource pool, and according to the demand, there will be various customization such as virtual factory, VE, VM tool, etc. Hence, it can be concluded that cloud manufacturing might lead to virtual manufacturing civilization.

2.3.3 Manufacturing as a Service and Providing of Capability Over the Entire Life Cycle

Cloud manufacturing supports a new business model that aids in the transformation of manufacturing industries from production to service-oriented manufacturing. The manufacturing services cover all stages of the life cycle of a product (Wu et al. 2013) as shown in Figure 3. Therefore, it concludes that cloud manufacturing service can be considered as "manufacturing as a service." As there is a large number of cloud manufacturing services when any user has any innovative idea, it can be converted into a physical product by using all the required manufacturing services and delivered to the user. This proves to be a great help to small enterprises which are having limited manufacturing resources that are so costly that they cannot afford them.

Fig. 3 Capability service (Wu et al. 2013)

2.3.4 Efficient Collaboration and Seamless Integration

Interconnection of shared manufacturing resources is made possible by the cloud which provides a shared platform helping in cooperation. A cyber business environment is created by the cloud manufacturing platform from where any supplier or demander can find the partner which meets their requirements. Also, a fundamental framework is provided by the cloud platform which manages the material and capital flow that occurs during an interaction between members. As shown in Figure 4, a shared service pool is formed where a large range of services gather, and based on requirements, various subtasks can be accomplished by integrating the interoperable services.

2.3.5 Manufacturing with a High Level of Knowledge and Collective Invention

Since one of the most essential variables in business rivalry is innovation, cloud manufacturing places a premium on knowledge reuse and innovative manufacturing. The manufacturing cloud can be considered a pool of multidisciplinary knowledge.

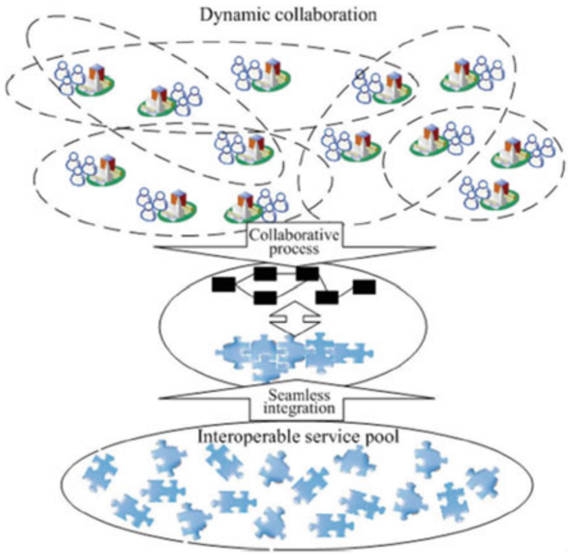


Fig. 4 Collaboration and integration (Wu et al. 2013)

Apart from knowledge, AI technologies are also required to make necessary decisions. As shown in Figure 5 both knowledge and AI technologies support product and service life cycles (Ren et al. 2017). In the product, life cycle knowledge and AI help in innovation and improving the efficiency of various stages such as design, production, simulation, whereas they support various stages in the cloud service life cycle including service description, scheduling, and other phases. It is quite evident from the figure that knowledge can come from any user may it be craftsmen or any expert. Thus, a social platform is offered by the cloud through which ideas can be shared and talents can communicate.

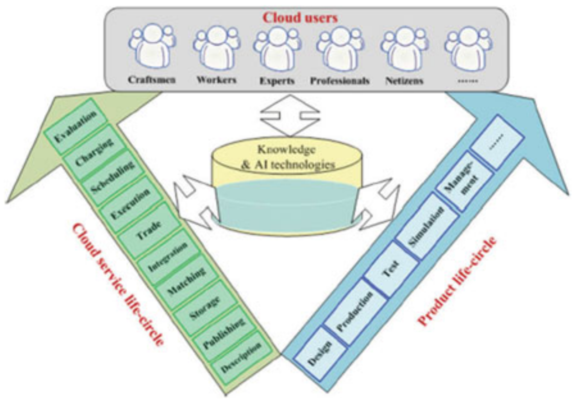


Fig. 5 Knowledge-intensive manufacturing (Ren et al. 2017)

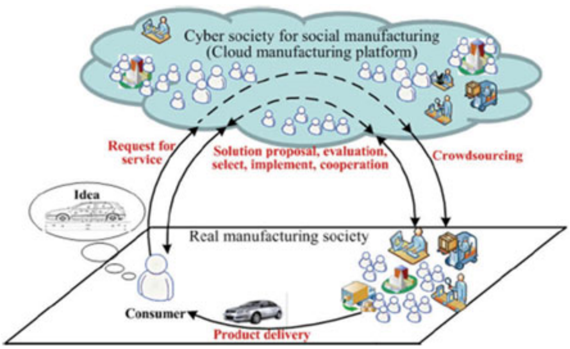


Fig. 6 Crowdsourcing (Wu et al. 2013)

2.3.6 In the Direction of Future Social Manufacturing

Social manufacturing is a phenomenon in which everyone may completely engage in all stages of a product's life cycle, thanks to cloud technologies (Wu et al. 2013). It will play a major role in enabling a highly personalized product from imagination to reality at a lower cost, enhanced quality, and increased agility. Figure 6 shows how crowdsourcing can be done in social manufacturing. When a customer has a hazy concept about a product, he or she can upload it to the cloud and submit a service request. Various experts with appropriate knowledge can submit their solutions on the cloud platform, which are then accepted and integrated to coordinate the required resources after being evaluated by the customer. Finally, after the product is produced it will be delivered to the customer via a logistic network that too would be available on the cloud platform.

2.4 User Model in Cloud Manufacturing

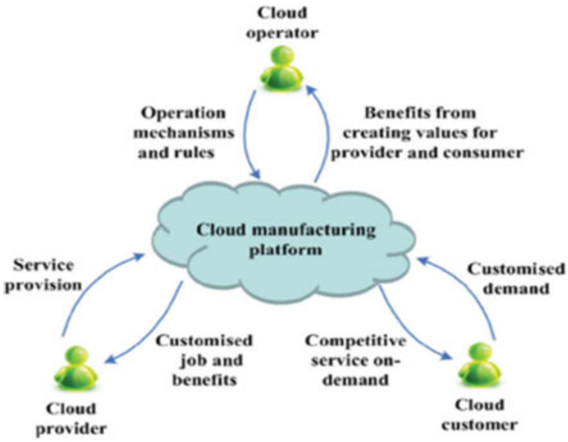
Figure 7 displays the various types of cloud manufacturing users and their relationships. The key participants in cloud manufacturing are the cloud provider, cloud customer, and cloud operator.

Cloud provider: The entity which provides manufacturing resources, as well as capabilities in form of service, is known as cloud providers. They also acquire customized jobs as well as comprehensive benefits via a cloud manufacturing platform.

Cloud customer or consumer: A demand for any application in the product life cycle is made by the cloud customer. The on-demand service is offered through a cloud manufacturing platform, which ensures that the services provided are competitive in terms of cost, innovation, business agility, and productivity.

Cloud operator: The entity which operates the cloud manufacturing platform is known as the cloud operator. All the technical processes and business strategies are

Fig. 7 Users in cloud manufacturing (Ren et al. 2017)



set up by cloud operators. Along with it all the business transactions, supply, and demand of services, as well as social networks of the cloud provider and operator, are managed by the cloud operator (Ren et al. 2017).

2.5 Factors Driving Cloud Manufacturing Implementation

The elements that drive cloud manufacturing implementation have been classified into four parts: scope, enterprise, industry, and technology.

Scope: Cloud manufacturing can be disposed of as a private cloud, a community cloud, a public cloud, or a hybrid cloud across an organization, a country, or even the entire globe. A private cloud is less complicated to set up than a communal cloud or another type of cloud (Low et al. 2011).

Enterprise: When cloud manufacturing is implemented in any enterprise its success depends on the adoption and participation of the whole enterprise. The factors which affect the enterprise to adoption and participation are understanding of top management and their support, enterprises objectives and business requirements, enterprise size, and adequate knowledge and information to the employees and their cooperation (Low et al. 2011).

Industry: The manufacturing sector consists of numerous industries, and each industry has its process and characteristics and is also at different stages of development which eventually leads to a different degree of requirements, difficulties, and complexities for the implementation of cloud manufacturing (Low et al. 2011).

Technology: In the cloud manufacturing process, each technology, for example, has a specific purpose. Building cloud platforms necessitates the use of IoT, while managing and operating cloud manufacturing necessitates the use of other technologies, and some technologies have an impact on an organization's desire to embrace (Low et al. 2011).

2.6 Problems Faced by the Implementation of Cloud Manufacturing

The term "cloud manufacturing" is still a bit of a misnomer. The current definition of cloud manufacturing perplexes individuals as to what it is, how it may be done, and what its benefits and cons are. To address this, the notion of cloud manufacturing should be broken down into simpler components and a simplified definition provided.

Owing to the naked truth that cloud manufacturing is an almost new idea, most businesses are unfamiliar with it (Zang et al. 2016). In addition, cloud manufacturing's success is contingent on enterprise adoption and engagement. As a result, it will take time for businesses to grasp the concept and put it into practice. There are various conditions for cloud manufacturing implementation that the company lacks, as well as an analysis of the cost of implementation, risks, and advantages that must be completed.

Cloud manufacturing is an amalgamation of many technologies (Li et al. 2011) a hierarchy needs to be developed as to which technologies to be used at which stage of implementation of cloud manufacturing and also clarification needs to be done regarding the core technologies and the supporting technologies.

2.7 Future Perspectives

Hierarchy and classification of technologies in cloud manufacturing need to be discussed, i.e., which technology will be needed at what level of implementation and which should be developed up to what maturity level (Wang et al. 2012).

The degree of enterprise involvement is determined by the degree of cloud manufacturing deployment. For example, at a junior level, a business would deploy cloud manufacturing to a lesser extent, so what amount of involvement would be necessary from the company, and what changes would be required if the degree of cloud manufacturing implementation was increased in the future.

Prerequisites and changes in the architecture of enterprise for implementing cloud manufacturing (Liu et al. 2017). As the majority of the resources would be virtualized some changes in the architecture of the enterprise at management as well as operation level are evident so what changes need to be done should be studied and presented.

Development of evaluation index helps in determining the maturity of the cloud manufacturing system. As the utilization of cloud manufacturing is a slow and progressive process evaluation index is needed to keep track of the progress of its implementation.

3 Conclusions

As cloud manufacturing is a relatively new idea, its goal, scope, boundaries, and capabilities are currently unknown. A comprehensive review of cloud manufacturing technologies for Industry 4.0 was conducted in this paper. In the current study, numerous technologies which contribute to the development of the notion of cloud manufacturing, as well as the interrelationships between them, were outlined in detail as follows:

- Cloud computing, in particular, is the most essential enabling technology since it lays the groundwork for the development of the cloud manufacturing idea.
- The elements that drive cloud manufacturing implementation have been divided into four categories: scope, enterprise, industry, and technology. Also, the issues faced by industrial implementation have been discussed and presented.
- Although research has been going on in this field for a long time, still there are some future perspectives that are yet to be researched and analyzed like there is a need to develop a hierarchy of technologies, changes in the architecture of industry for implementing cloud manufacturing, and also an evaluation index which would help to understand the level of maturity of cloud manufacturing have been listed.

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