Cloud Development and 3D Printing

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The United Nations (UN) 2030 agenda on sustainable development goals (SDGs) encourages us to implement sustainable infrastructure and services for confronting challenges such as large energy consumption, solid waste generation, depletion of water resources and emission of greenhouse gases in the construction industry. Therefore, to overcome challenges and establishing sustainable construction, there is a requirement to integrate information technology with innovative manufacturing processes and materials science. Moreover, the wide implementation of three-dimensional printing (3DP) technology in constructing monuments, artistic objects, and residential buildings has gained attention. The integration of the Internet of Things (IoT), cloud manufacturing (CM), and 3DP allows us to digitalize the construction for providing reliable and digitalized features to the users. In this review article, we discuss the opportunities and challenges of implementing the IoT, CM, and 3D printing (3DP) technologies in building constructions for achieving sustainability.

Keywords: 3DP technology ; 3D-PCP ; building construction ; cloud manufacturing ; Internet of things (IoT) ; sustainability

1. Introduction

The United Nations has set a target of achieving the sustainable development goals (SDGs) by 2030 in order to establish a sustainable environment [1]. Concerning the construction industry, the SDGs are “Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation (SDG 9)”, “Make cities and human settlements inclusive, safe, resilient and sustainable (SDG 11)”, “Ensure sustainable consumption and production patterns” (SDG 12), and “Take urgent action to combat climate change and its impacts (SDG 13)” [2]. Moreover, the construction industry is contributing approximately 13% of the world’s gross domestic product (GDP) [3][4]. As per the United Nations (UN), the construction industry is responsible for 12% of global drinking water consumption, 40% of global energy consumption, 40% of solid waste production, and 28% of global greenhouse gas emissions (GHG) [5][6]. The reports indicate that there is a necessity to implement sustainable technology for reducing the impact on the environment. Generally, in the construction industry, the amount of waste and energy generated is high [7], so with the evolution of 3D printing (3DP), some of the work processed in traditional mechanisms, such as concrete mixing, building blocks, and labor, can be replaced with 3DP. Professionals, government officials, and academics conclude that sustainability in the construction industry is a top priority [8] in dealing with environmental and ecological issues, as well as social, economic, and technological sustainability issues for sustainable development [9]. Therefore, sustainability in construction is typically viewed in terms of the tripartite domains: environment, society, and the economy. Unlike the traditional construction process, 3DP technology has been proven to be an efficient approach in architecture, engineering, and construction (AEC). Moreover, 3DP is of significant assistance in terms of economic development, environmental safety, manpower, time reduction, and customization of the complex architectural designs [10]. At present, 3DP technology (also called additive manufacturing or rapid prototyping) has emerged as a fast-growing technology due to its efficient manufacturing abilities and wide applications in different sectors. This technology creates physical objects by layering the materials based on the digital model [11][12]. As such, 3D printing services are feasible for geometrically complex and small-batch products. Moreover, the necessity for design information in 3DP to be available in a digitized format (.STL file), encourages us to realize digitization more generally. Moreover, the Internet of Things (IoT) and cloud manufacturing (CM) empowers us to implement digitization throughout the 3DP process [13] Additionally, to expand the efficiency of 3DP resource utilization and the variety of 3DP services, a cloud platform has been established [14][15][16]. CM is a modern network manufacturing mechanism that combines manufacturing technology and IT, including cloud computing [17][18] Big Data [19][20], and the IoT. Depending upon the concept of collaboration, intellectualization, materialization, servitization, and virtualization [21], CM provides high-quality, reliable, on-demand and cost-effective services across the network of manufacturing for complete cycle [22]. The most significant aspect of cloud manufacturing is the accumulation and vast exchange of manufacturing tools. Contemporary manufacturing methods require process design from design to machining, but the design of processes does not require standardization and several iterations for the team of design and machining. Complex computing in conventional manufacturing encounters significant challenges in the in-depth research of CM [23].

2. 3D Printing (3DP)

The construction industry requires a technology that could enhance productivity and automation with minimum impact on the environment. At present, the mechanism and method following in the construction industry are generating a large amount of waste that has a considerable effect on the environment and the cost of the projects. Formworks in traditional construction are a major source of expenses due to higher labor costs, machinery, material costs, and waste materials. Generally, forming a basic geometrical configuration during a formwork costs around 35% of the total cost of the project [24]. The productivity of the workforce for formwork faces challenges during the establishment of complex geometrical shapes. The fundamental activities involved in the conventional construction are presented in **Figure 1**. Given the amount of concrete mixing, the number of blocks is not accurately measured during their construction and, moreover, this requires a skilled workforce and many tools.

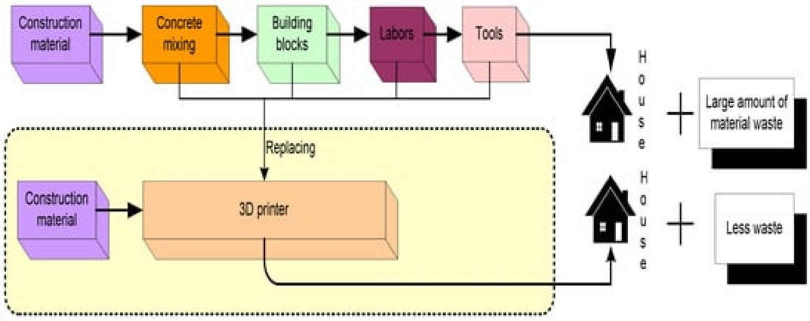

Figure 1. Conventional mechanism vs. 3D printing (3DP) mechanism in construction.

A large amount of the waste is generated due to inaccurate calculation and planning during the construction. The rise of 3D printing technology provides assistance for replacing concrete mixing, building blocks, labor, and tools, as these activities are the primary causes of increases in cost and the generation of large amounts of waste. 3DP technology cuts down the cost of the workforce on the project by 25% [25] and cuts the material cost by 65% compared to conventional construction methods [26] The widespread utilization of the 3DP also enhances the workers' productivity and safety in high-risk activities. 3DP's primary reliability rests on printing technologies, material properties, and the expert management of the work [27][28]. A typical feature of the various processes in the additive manufacture is the development of a limited number of steps in the fabrication process for transforming the 'idea' from the production to a finished product [29]. **Figure 2** illustrates the phases/steps that are involved in the 3DP process. Initially, we need a conceptual model on the 3D CAD application; after that, a .STL file (Standard Triangle Language or Standard Tessellation Language) and G code are generated. After these stages, the manufacturing process is initiated and, in the final stage, cleaning and post-processing will be completed.

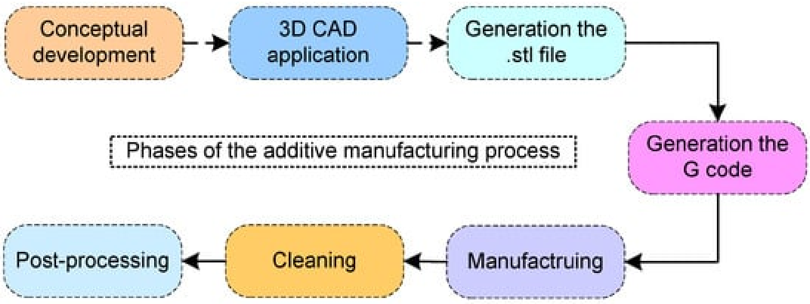

Figure 2. Phases of the 3DP process [27].

3DP technology can be regarded as eco-friendly technology that offers infinite opportunities to realize geometric complexity [30][31]. 3DP can be used in the construction sector to print whole houses or to produce building parts [32][33]. With 3DP, organizations facilitate the following features: quick, inexpensive design and visualization of the virtual building, prevention of delays, and help identifying any problem areas [34]. Simultaneously, 3D printing technology allows construction engineers and their clients to interact more quickly and clearly. Many of a customer's demands are derived from an idea, and 3D printing makes it easy to manifest the concept beyond the outdated system of paper and pencil [35] Apis Cor Printed House in Russia [36] and Canal House in Amsterdam are two examples of 3D printed houses.

Figure 3 presents the significant interdependency of multiple parameters of 3DP for construction. To effectively enforce 3DP in a large-scale structure, the following are three primary parameters to be discussed.

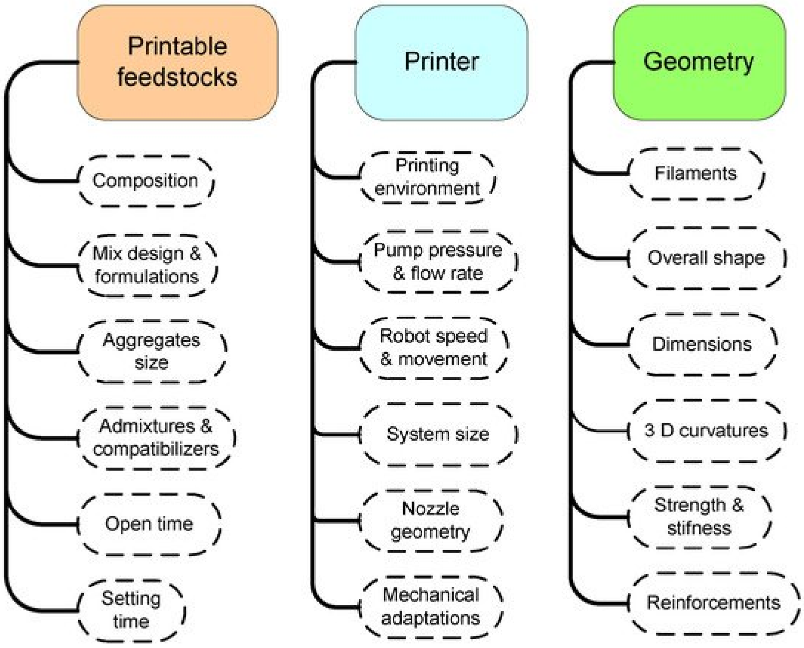

Figure 3. Relationship of systematic parameters for large-scale AM implementation in construction.

(a)

Printable feedstocks: In the context of the essence of feedstock developments, the source structure, mix model with various additives, and specific size contribute to the effect. To maximize the effectiveness of mixing materials, an accurate opening time and setting time are needed for allowing the continuous extrusion and distribution to the dust. For maximizing the mixing of feedstocks, it is essential to provide the required open period and time to allow continuous extrusion and distribution to the nozzle.

(b)

Printer: Pump-integrated printers are essential for the scale of production in the construction industry. The pressure and flow rate must then be examined following the various mixing designs. To obtain a reasonable output, i.e., smooth finish, square edge, and dimensional accuracy, the printer's speed, and size are also essential. The deposition rate of feedstocks determines construction speed, and the reduction in the setting time will lead to a significant risk of hardness inside the printer system. An integrated printing device should continuously extrude the material with continuous feedstock materials to avoid the interface between the layers.

(c)

Geometry: The custom design and the effects of the existing two criteria will be used for specifically applying smart self-reinforced geometry to complete realization of scaling building blocks/objects. The strength and rigidity of the printed object/blocks could then be obtained by the type of stiffness, deposited filaments and 3D curvatures, and truss-like structure [37].

3. CM and 3DP Based Construction of Buildings

CM and 3D printing show tremendous impact in the design and manufacturing process and trending research areas in innovative manufacturing technology. In this section, initially, we will discuss the importance and working of CM and 3D printing. After that, we will address the 3D printing-based service architectures clearly, and finally, the section concludes with the cloud printing service system.

3.1. Cloud Manufacturing (CM)

CM is a network manufacturing mode that provides users various on-demand manufacturing services according to users' needs [38][39]. This mode uses the network to organize the online manufacturing resources. CM is an Internet-based manufacturing mode that delivers users with a spectrum of on-demand manufacturing services to meet users' needs [40][41]. This approach utilizes the network to coordinate online manufacturing tools. **Figure 4** shows a representative CM architecture in current researches. The manufacturing service providers deliver all sorts of development tools in cloud service through perception and virtualization technology for the entire product life cycle [42][43]. Manufacturing service applicants apply manufacturing specifications for each level or different granularity development service requirements for the complete product life cycle to the cloud platform, seeking to identify manufacturing services that already exist on the cloud platform [44][45]. The customer's responsibility as a manufacturing service provider or a requesting organization is dynamically evolving [45][46][47][48]. When one offers a production service, he is a retailer of services in the CM system. The cloud platform administrators control and run the cloud platform effectively and organize the interaction between the manufacturing service requesters and the manufacturing service providers. Operators can dynamically and flexibly ensure that service for resource users is based on access requests by resource users. The essence of the CM process is the delivery of production resources between supply and demand, and the operation of the cloud is primarily to manufacture as a service [49][39][50].

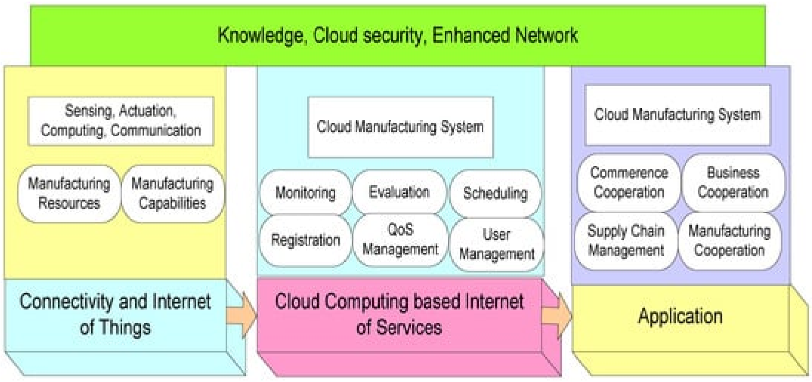

Figure 4. Architecture of CM system.

3.2. CM Assisted 3DP

Globally, the impact of the construction industry on the environment is very high in terms of energy consumption, waste generation and emissions of greenhouse gases [51]. Currently, society is aiming to find sustainable technologies which can reduce the burdens of traditional construction approaches. 3D printing has emerged as a sustainable technique for this purpose. More innovations will bring this technology into the mainstream of buildings formation and construction processes [52]. Through this technology, the additive construction strategies facilitate topology optimization, reduce the use of materials, produce complex geometries without supporting structures and, more importantly, accumulate and integrate complex technologies in a single platform. This practice is not possible in traditional construction mechanisms [53]. Customization is achieved in complex structures by computer-aided design and improved fabrication processes. The construction complexes have been possible through digital technologies and improved material science [54]. The industries involved in building construction are moving towards digitization and adopting the 3D printing technology to convert the virtual model into an accurate model. Productivity has been increased with a reduction in operating cost by this technology for building construction [55][56].

CM and 3DP research have been a topic of extensive research in recent years in manufacturing. The 3D printer-based cloud development system and underlying manufacturing equipment are essentially a modern mode of manufacturing that substitutes mass production.

3.3. Architecture for 3D Printing Cloud Platform Service

3DP integration with CM will foster the growth of potential intelligent networks of virtual 3D cloud printing and establish a modern service-driven 3D printing manufacturing mode to accomplish the mass customization options. The service mode demonstrates the cloud printing device architecture and service flow. 3D-PCP device architecture was classified into six layers based on parameters of resources and their access, layer CM application system, and task management and execution. The first layer comprises cloud scheduling, QoS management, evaluation monitoring manufacturing, and registry allocation. The second layer includes supply chain co-operation, portals commerce co-operation, manufacturing (Mfg) co-operation, and business co-operation. The third layer comprises communication Mfg resources, Mfg resources and capability perception, connection, and layer application on-demand use and co-operation. The fourth layer includes management service, interface service generation and aggression, IoT connection and communication knowledge, cloud security, wider network, and cloud computing-based Internet services. The system architecture is divided into five layers: the interaction layer, service layer, the core layer, task layer, and applications layer, in Selection Distributions Manufacturing mode (CDM) [57] suggested by the Academic Lu team of the Chinese Academy of Engineering.

The physical layer comprises the manufacturing resources, access, and virtualization, while the service layer operates in a similar context as the control layer, core layer, and task layer. At the same time, several architectures on the 3D cloud Printing Platform consider virtual resource layers as the core components of virtual resource pools for multiple homogenous nodes. The service aggregation layer permits the configuration of service and internal calls for virtual resource pools while delivering lifecycle resources, including workflows. In another architecture, all physical and interface devices are differentiated on distinct levels. The user tool layer is assigned as part of the service layer's functionality [58]. In [59] an agent layer to the architecture establishes a bridge between the resource demand side and the supplier. The agent layer contains the supplier of the cloud output and the demand side of the operation, the system operating connection as shown in **Figure 5**. A service integration architecture was developed to complete service integration [60] and it includes a physical system layer, adapter layer, service layer, control layer, and application layer. The architecture is only for the convergence of services, and the first four layers include the virtualization, servitization, and control of manufacturing infrastructure and fulfil the resource layout and compete. On the other hand, the architecture of 3DP OS [61] and 3D framework [62] for manufacturing tools have been built based on IoT and presented; namely, the resource layer, perception layer, network layer, service layer, and application layer. Furthermore, several researchers have suggested the architecture of the associated service models in the field of training [63] conventional valve manufacture [64] miniature manufacturing [65] and other areas.

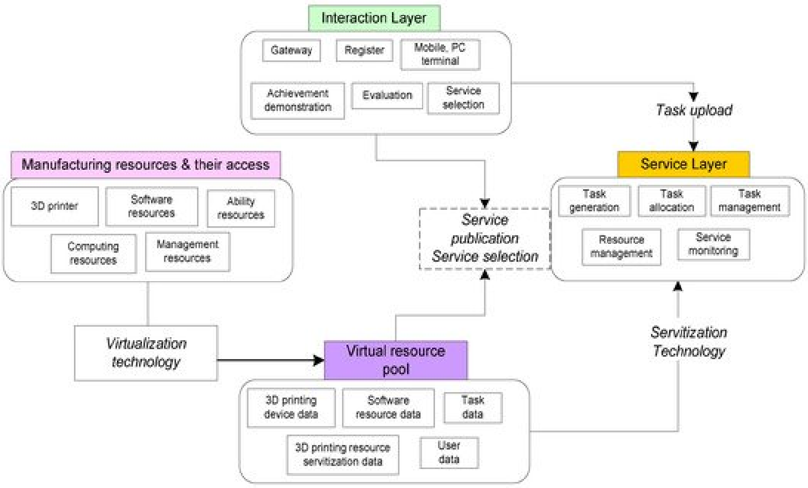

Figure 5. 3D-PCP framework in recent studies.

Figure 6 provides the detailed mechanism of the cloud printing service system. Cloud printing service customers and cloud printing service providers are represented as the users in this system [66]. Cloud printing service customers request the printing of a model by providing the printing requirements. The request is sent to the cloud print service search engine for pre-processing and the details are sent to the cloud print service search to initiate the printing [67]. The cloud service provider delivers a database, application interface (API), and registration support for utilizing the services. Here, the cloud print search sends the request to the database and API, where it receives a message for continuing the process further on in the system. The cloud service queue refers to an order or line of these tasks that are waiting to be handled.

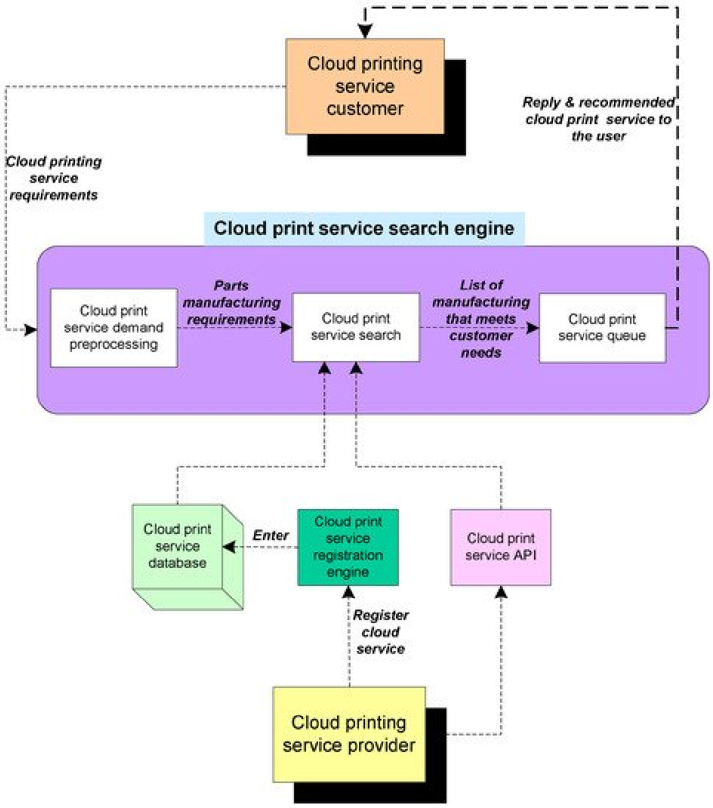

Figure 6. Cloud printing service system operation relationships [32].

3DP is adopted in various industries that are a part of Industry 4.0. The advantages of 3DP include less reduction in building time, reduced waste generation, and more flexibility in the manufacturing process to develop a complex design, which ultimately leads to a reduction of cost [68][69]. Additionally, automation in the construction process will help with better monitoring of the work, reduce manpower and manual labor involvement, and increase safety during the manufacturing process [70]. In addition, there are opportunities for the recycling and reuse of the printed materials when it is desired. Researchers have predicted that adopting this technology in the construction sector will open up incomparable design opportunities and merge construction technology with digital technology [71].

The 3DP process can be made more innovative by focusing on the technology-based research work with innovation, developing expertise in this sector, financial sustainability, unification, and encouragement of territorial equality [36]. The IoT can be incorporated in the construction technology for real-time monitoring of different parameters and the work area, enhancing safety precautions while the construction work goes on [37][72].

A sensor-based integration system is achieved in the IoT technology to gather and monitor the data remotely. There are many pieces of evidence that exist regarding the incorporation of IoT technology for smart building construction. Another digital technology that can help build construction is the artificial intelligence (AI) network [73]. AI in construction refers to machines involved in undertaking tasks as though they have human skills, planning, self-correcting, reasoning, etc.

One more piece of technology that can revolutionize the construction industry is big data analysis (BDA). Big data includes the information that the existing tools cannot store, retrieve, or analyze concerning the processing speed, volume, and the range of data [74][75]. It is predicted that big data can be used to improve the output of the BIM model and thus increase its efficiency [76]. Almost all core technologies in the 3D–PCP service period are included, as seen in **Figure 7**, in the five aspects of the study. The next section summarizes the emerging trends and service structures in the successful 3D–PCP global sector. We include a resource for researching 3D printing platforms via comparisons of each platform.

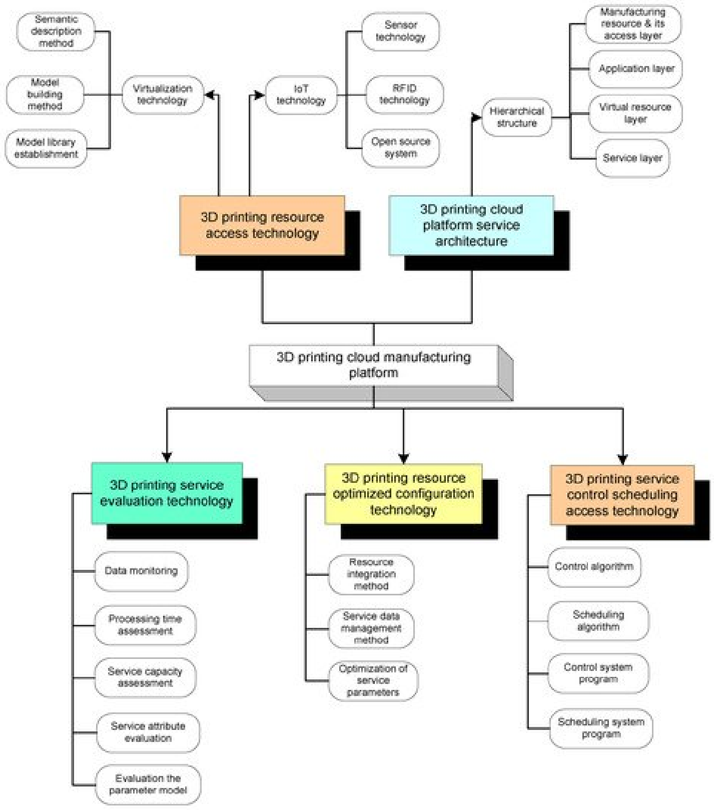

Figure 7. CM based 3DP platform.

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