Advances in Engineering Software 81 (2015) 66–72

Contents lists available at ScienceDirect

Advances in Engineering Software

journal homepage: www.elsevier.com/locate/advengsoft

Collaborative design in the era of cloud computing

Georgios Andreadis [a,*], Georgios Fourtounis [b], Konstantinos-Dionysios Bouzakis [a]

[a] Mechanical Eng. Department, Aristotle Univers. of Thessaloniki, Greece
[b] Megasoft, Serres, Greece

ARTICLE INFO

Article history:
Received 19 August 2014
Received in revised form 15 October 2014
Accepted 18 November 2014
Available online 13 December 2014

Keywords:
Collaborative design
Drawing
CAD
Cloud computing
Server
Mobility

ABSTRACT

The paper describes the application of the latest Information Technologies in business processes such as design and manufacturing. More specifically it examines the use of cloud computing in the mechanical drawing and design process of an enterprise. It proposes a specific architecture with different servers, for the implementation of a collaborative cloud based Design system. Finally as an application example, it compares the operating cost of an industry's design department before and after the use of the proposed system. This example uses a private cloud deployment model so that the comparison of the operating cost would be feasible. While public cloud may offer more functionality and economy, private cloud is best suitable to make conclusions and comparison between on-premise and cloud operation, because all of the cost is handled by the organization that uses it.

1. Introduction

Despite the dramatically increasing penetration of cloud computing to industries [1–3] in recent years, many design departments stay out of it. The main reason seems to be the reluctance of users on the response times of applications. In CAD software, direct interaction with the user is vital and any delay between the command of the user and the graphical effect causes the rejection of the system.

Cloud computing however, has introduced a range of new services [4–6] and features that could improve the functionality of a design department, while new technologies have recently emerged promises to eliminate CAD users objections.

Paper [4] presents a new algorithm (Ranking Chaos Optimization) so that cloud services and computing infrastructures can then be quickly combined and shared with high efficient decision which is critical in virtualization.

Paper [5] utilizes virtual machines to remotely draw parametric design blocks to CAD software with no user interaction and compares the cost for cloud computing vs in-house regarding the hardware used.

Paper [6] also utilizes virtual machines to remotely draw parametric design blocks to CAD software with no user interaction and also introduces a ticketing system to coordinate execution.

Present paper moves forward transferring all CAD services to the cloud. It proposes a new infrastructure architecture that would be sufficient to support remote (cloud) execution. The design of the proposed architecture takes, in addition, into account new techniques that have been evolved recently (application virtualization, Graphics acceleration using GPU pass through) in order to design an infrastructure capable to satisfy the needs of CAD users.

The major challenges that a design department faces are the following:

- Application availability

The classic way of software disposal (license per user/workstation) raises an important issue regarding the operation cost of the department. In fact while software is installed in a number of workstations, it is used simultaneously by a smaller number of them. For example finite analysis software can be installed on all workstations of civil and mechanical engineers of the department, but only a few of them will use it simultaneously. Usually the solution given to the problem is to install the software in a small number of workstations that will be used alternately by the engineers. Obviously this is a compromise and not the desirable solution.

- Frequent software updates

In order to be competitive and efficient, the design department should frequently upgrade the software used so that it benefits from the new features offered by the new versions. New versions

* Corresponding author at: 24 Papapetrou str., 55131 Thessaloniki, Greece. Tel.: +30 6938852200 (M), +30 2310996355 (O).
E-mail address: andreadi@eng.auth.gr (G. Andreadis).

http://dx.doi.org/10.1016/j.advengsoft.2014.11.002
0965-9978/

should be installed in a multitude of workstations with different characteristics and possibly operating systems. This leads to high maintenance costs because apart from the cost of the upgrade it requires the involvement of one or more specific IT specialists.

- Requirement for powerful workstations

CAD applications require significant computing power from both the workstation's CPU as well as the GPU. In fact they are considered as the most demanding applications regarding the computing power of a workstation. The ever increasing software requirements require hardware equipment updates more frequently than other departments.

- Custom solutions – Libraries

During the operation of the design department custom add-in applications and drawing libraries are created or purchased. A custom application could be, for example, software which will design three-dimensional parametric stairs or gears, while design libraries could be furniture, trees, etc. These applications, libraries, revisions and the latest versions of these are desirable to be available in all the workstations of the design department. This implies a very large workload in departments without access to the same servers (need to exchange files with emails – installation on workstations, etc.) and of course, greatly increases the probability of errors.

- Collaborative design

Collaborative design is a key challenge for a design department as more engineers or other specialists are involved in the design process of a product. Thus, for the design of a building, architects will design the architectural design (CAD), civil engineers will implement the static analysis (CAE), mechanical engineers the mechanical study (CAE/CAD), etc. These studies and designs interact with each other (e.g., static analysis may enforce reviewing the architectural design) while more than one people are likely to be engaged in individual studies. Additionally the physical location of those involved in the study may not be in the same place or office but instead in different cities or countries.

- Backup policy/data disaster recovery

Projects and studies are the "property" of a design department and preserving them is a (though usually underestimated) very critical process. Most often the maintenance of the process relies to the engineers without having established a standard policy. Even the most organized departments, where all files are stored on a central server; this is done at the local office and not for the whole department. Applying a backup policy which will ensure full restoration of files in case of failure requires special additional equipment and specialized IT services.

- Mobility

A particularly important issue is mobility. Employees of a design department are people who move frequently for in place supervision of a project or for collaboration with third parties (customers, partners) in their offices. So very often arises the need for full or partial access to drawings of the project. This remote access needs to be implemented through the engineer's laptop, the client's workstation or even a mobile device.

- Security

A design department faces all security issues [7] posed by exposure to the internet. To deal with intrusions from the Internet requires a high level of IT staff and expensive software. Even more especially complicated is the issue of access rights to files in order to ensure confidentiality simultaneously with functionality.

- CAM

When the final stage of a design project concerns CAM arise issues regarding transfer of new projects to the respective facilities, categorization of existing designs and access to them.

The paper tries to answer to these challenges, examining the use of cloud computing in the mechanical drawing and design process of an industry. It proposes a specific architecture with different servers, for the implementation of a collaborative cloud based Design system. Finally as an application example, it compares the operating cost of an industry's design department before and after the use of the proposed system.

The paper has the following structure: Section 2 defines the basic cloud principles, while a brief discussion about cloud based CAD is held in Section 3. The proposed System's approach is presented in Section 4, and its advantages and characteristics are described in Section 5. In Section 6 an application example is shown, comparing the operating cost of an industry's design department before and after the implementation of the proposed system and finally Section 7 provides conclusions and future work.

2. Cloud principles

According to the National Institute of Standards and Technology (Special Publication 800-145), "cloud computing is a model for enabling ubiquitous, convenient, on demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model is composed of five essential characteristics, three service models, and four deployment models". In the same publication the service and the deployment models, are described as:

"Service models:

Software as a Service (SaaS).

The capability provided to the consumer is to use the provider's applications running on a cloud infrastructure.

Platform as a Service (PaaS).

The capability provided to the consumer is to deploy onto the cloud infrastructure consumer-created or acquired applications created using programming languages, libraries, services and tools supported by the provider.

Infrastructure as a Service (IaaS).

The capability provided to the consumer is to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications.

Deployment models:

Private cloud.

The cloud infrastructure is provisioned for exclusive use by a single organization comprising multiple consumers (e.g., business units). It may be owned, managed and operated by the organization, a third party or some combination of them and it may exist on or off premises.

Community cloud.

The cloud infrastructure is provisioned for exclusive use by a specific community of consumers from organizations that have shared concerns (e.g. mission, security requirements, policy and compliance considerations). It may be owned, managed and operated by one or more of the organizations in the community, a third party or some combination of them and it may exist on or off premises.

Public cloud.

The cloud infrastructure is provisioned for open use by the general public. It may be owned, managed, and operated by a business, academic, or government organization or some combination of them. It exists on the premises of the cloud provider.

Hybrid cloud.

The cloud infrastructure is a composition of two or more distinct cloud infrastructures (private, community, or public) that remain unique entities, but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load balancing between clouds)."

From the Essential Characteristics of the Cloud definition, especially important for CAD users are: On-demand self-service so that they may access the provided services as needed, Resource pooling so that they may benefit from the economy supplied by sharing the available physical or virtual resources and Rapid elasticity so that they may rapidly scale the provided services as required.

Furthermore Private cloud can be used from an organization for its own needs while Public cloud can be used by a service provider in order to serve multiple organizations or individual users.

3. Cloud based CAD

As mentioned earlier the main problem in using cloud for CAD applications is the smooth interaction with the user. For the solution of this problem there are three main factors. First, the connection speed (bandwidth), second special thin-clients (traditional browsers are not enough) and third special server infrastructure.

Regarding the first, existing (ADSL, VDSL) internet speed is sufficient, when combined with new techniques and topologies that already have appeared.

Application virtualization systems are the core of the solution. The basic principle of these systems is simple and consists of the following: the application runs entirely on a server. The user uses a thin-client software which serves only as an input (keyboard, mouse or other input devices) and output (monitor, etc.) data. All calculations and data management are done on the server and only the visible result is returned to the user. This means that the only network traffic data consists of keyboard strokes, mouse clicks and pixel changes.

A major advantage of this technology is the fact that the thin-client can operate in a variety of operating systems and devices. As long as the server is compatible with the requirements of the CAD application it is possible to be executed on a PC running windows, mac OS, Linux or else even on old PCs up to netbooks, tablets or mobile phones.

The implementation of a system based on Application virtualization could be applied by an organization who will be using it for internal use (private cloud) or a provider who will rent the services (offered software) to third parties (public cloud).

Of course a proposed architecture should take into account not only the functionality but also the cost.

4. Proposed architecture for the collaborative Design system

The proposed architecture consists of the following servers:

Web server

On this server is located the portal of the system. It is the initial point of entry to the system and also the one on which auxiliary and servicing work is operated. Thus it consists of a number of subsystems in which users have access depending on their rights.

Application servers

In application servers are located the CAD/CAM/CAE applications. They are servers that will physically execute these applications. Each executing application constitutes a session. Special virtual application software executes the application while transferring output data to the client (monitor–printouts, etc.) and receiving input (keyboard–mouse, etc.).

Coordinator servers

These are servers that route the request of a user to execute an application to the most suitable application server. They supervise continuously all the available application servers regarding open sessions and they choose the one with the least load. Then they give the command to execute the application and redirect the user to the application server.

Database/storage servers

These are special servers with storage capacity of high-speed data transfer and high security (RAID 10). Used to store user data (design files) and also for hosting databases that are necessary to operate the system.

GPU servers

Special servers with high standards graphics hardware which undertake the calculation of complex technical graphics imaging (e.g. rendering) using Pass Through technology. In fact they constitute the graphics card for each session opened by an application server and have high graphics requirements.

Calculation/external modules servers

These are special servers with high standards hardware regarding mathematical calculations which undertake complex mathematical calculations (mainly regards CAE applications). These servers can also execute external add-in modules of the applications in order to relieve the application servers.

All the above mentioned servers can be either physical machines or VPS (Virtual Private Servers) and they can exist in one or more data centers. The topology of the architecture is shown in Fig. 1.

The basic sequence of system processes is:

- The user is connected via a thin-client to the web server.
- The user logs to the system.
- The user selects the application (CAD) which he wants to execute.
- The web server addresses to a coordinator server.
- The coordinator server selects the application server to which the application will execute and informs the web server.
- The web server redirects the user to the application server.
- The application server opens a new session and executes the application.
- The user interacts with the application.

5. Advantages – Characteristics of the proposed system

The challenges that an industry faces was mentioned in the Introduction. Using those challenges as criteria, a description of the advantages and the characteristics of the proposed system is following

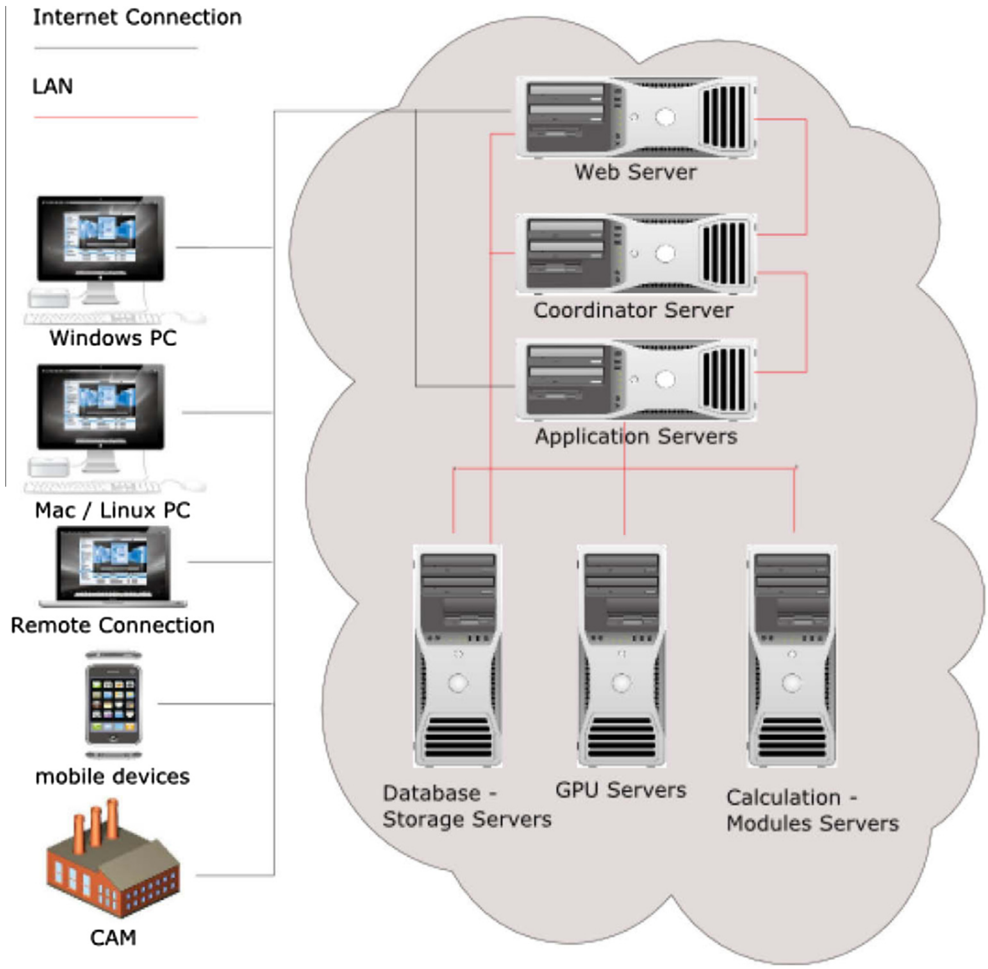

Fig. 1. The proposed architecture.

- Application availability

The number of licenses to be purchased by the department depends on the maximum number of concurrent users and not by the total number of users. This means fewer expenses.

- Frequent software updates

Software upgrades should be performed at the same rate, but the fact that the number of them is smaller and the number of their installations even smaller (a server serves at least 3 workstations) lowers both cost and complexity.

- Requirement for powerful workstations

Workstations no longer need to be powerful since their role is limited to data input–output handling.

- Custom solutions – Libraries

A centralized system can be much more easily configured for the best operation (e.g. libraries are directly accessible by all users, while custom add-in applications are installed once).

- Collaborative design

The really strong point of the proposed architecture is the potential it offers in terms of collaborative design. Thus, the project manager can define which users may have access to specific sections of the project, set permissions (read-only, allow changes, etc.) to designs per user or user group, invite external partners, give to the final customer permission to view selected designs with the ability to add comments. Additionally he can set alerts for changes in the designs so that all those involved can be quickly informed.

- Backup policy/data disaster recovery

The fact of concentration of all of the department's files in a specialized data center alone is the guarantee of safety from disaster. Moreover it is a much simpler procedure to back up the files in another data center.

- Mobility

The ability of the proposed architecture to execute on any platform is the definitive answer to this challenge.

- Security

Security from external attacks is "de facto" higher in a data center. The proposed architecture additionally offers greater security regarding the users of the system. The main advantage is that the ability to copy files to the workstations can be denied.

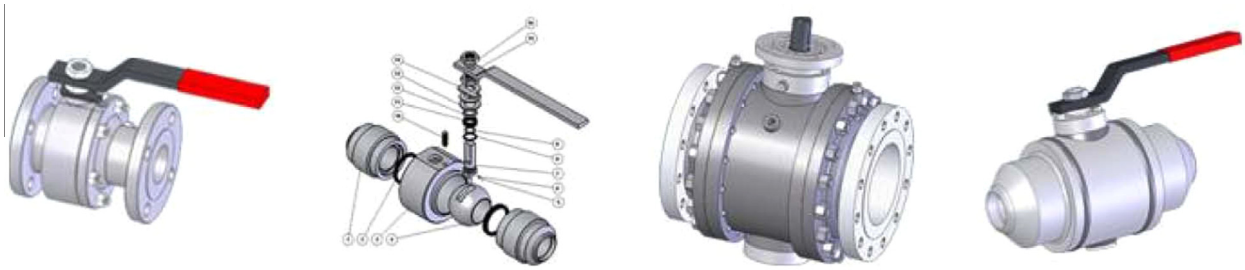

Fig. 2. Design examples.

- CAM

The management of the designs is done on the cloud (via web interface) resulting the immediate disposal at the CAM areas and their organization according to business needs.

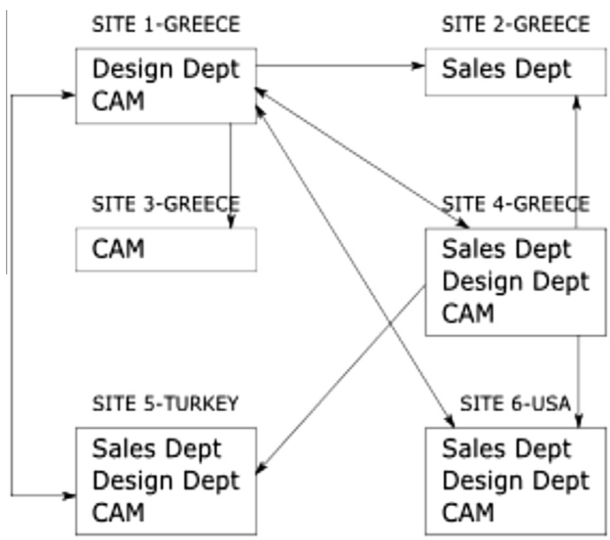

Fig. 3. Data flow between different sites of the company.

6. Case study

The examined industry is engaged in manufacturing valves and M/R Stations on demand. It has a design department which has spatially split its facilities around the world, and consists of two functionally distinct units which work together on specific projects. It also has a sales department which should have access to final and selected drawings and costs and also information on the progress of projects. This section is also divided into three different divisions due to the company's operation in three countries.

A sample of the company's designs is showing in Fig. 2.

The employees of the design department travel frequently between the countries of the company's operation and must have full access to the functionality of the department regardless of their geographic location. Also all designs and projects should be accessible by all authorized employees respectively.

The company often outsources parts of the designs and manufacturing to others, creating the need for authorized access to portions of the project data.

Each company's site is equipped with local area network, a data server and access to the internet.

All these compose a problem that the company faces today with email exchange between cooperators, raising safety issues, while remote work is treated with remote control software lacking performance due to low upload bandwidth (1 Mbps).

The schematic data flow between sites of the company is describing in Fig. 3.

In order to estimate the operating cost of the design department a period of 5 years is selected as more representative, since at that

Table 1
Design department current operating cost.

Design department current operating cost									
Cost description	Units per site						Total units	Cost per unit	Total cost
	1	2	3	4	5	6			
Hardware									
Power workstations	5			3	2	2	12	1000	12,000
Simple workstations		5					5	500	2500
Servers	1	1	1	1	1	1	6	2000	12,000
Software									
Application licenses	5			3	2	2	12	4800	57,600
Application upgrades	5			3	2	2	12	3800	45,600
Operating costs									
Workstations consumption[a]	5	5		3	2	2	17	156	2652
Server power consumption[b]	1	1	1	1	1	1	6	1752	10,512
IT Services – full time	1			1			2	90,000	180,000
IT Services – hired		1	1		1	1	4	12,000	48,000
Total cost									370,864

[a] Workstation power consumption = 5 (years) × 260 (days) × 8 (h) × 0.150 (kW/h) × 0.1 (E/kW h) = 156 E.
[b] Server power consumption = 5 (years) × 365 (days) × 24 (h) × 0.400 (kW/h) × 0.1 (E/kW h) = 1752 E.

Table 2
Necessary servers for the implementation of the proposed system.

Role	Specs	Cost per server/year	Number of servers	Total cost per year
Web server	VPS			
Coordinator server	2 cores, 3.2 GHz			
	8 GB RAM			
	400 GB	230	1	230
Application server	Dedicated			
GPU server	6 cores, 3.2 GHz			
Calculation/external modules server	24 GB RAM			
	2000 GB	1200	3	3600
Database/storage server	VPS			
	2 cores, 3.2 GHz			
	8 GB RAM			
	400 GB + 2000 GB	550	1	550

Comments
– The web server is also the coordinator server due to the limited number of users.
– The application servers are three so they do not have to serve more than three CAD users simultaneously. At the same time they play the role of GPU server–calculation/external modules server. They are also sufficient to serve the sales department (viewing only).
– For the operation of the system an application virtualization software is required.
– One IT specialist is sufficient for the whole company. However, the company will continue to need external IT partners per site.

Table 3
Design department cost using the proposed system.

Design department proposed architecture cost									
Cost description	Sites						Units	Cost per unit	Total cost
	1	2	3	4	5	6			
Hardware									
Simple workstations	5	5		3	2	2	17	500	8500
Cloud servers							5	4380	21,900
Software									
Application licenses							8	4800	38,400
Application upgrades							8	3800	30,400
Application virtualization							3	1000	3000
Operating costs									
Workstations consumption	5	5		3	2	2	17	156	2652
IT Services – full time	1						1	90,000	90,000
IT Services – hired		1	1	1	1	1	5	12,000	60,000
Total cost									254,852

time the equipment must be replaced with new. During the 5 years the software is expected to be upgraded at least once. The operating cost of the design department (involves only IT costs) for a period of 5 years is showing in Table 1.

6.1. Proposed implementation

The proposed implementation is based on the logic of the private cloud. That is, the company decides to implement its own system by hiring the necessary servers and undertake the installation of the required software and maintenance operation. This approach is chosen so that we can directly compare the operating cost of the proposed architecture against the current working model of the department.

A basic assumption is that from the total of 12 CAD workstations only 8 (maximum) will operate simultaneously.

Thus for the implementation of the system the following servers are required (Table 2).

The operating cost of the department is formed as shown in Table 3.

It seems therefore a significant reduction in operating cost (254,852 Euros vs. 370,864 Euros) over a period of five years, which if combined with the benefits in the way presented above, making the solution particularly attractive.

7. Conclusions – Future work

A collaborative Design system using cloud computing was examined. Cloud computing can now support CAD applications, offering increased functionality while reducing operating cost. Nevertheless there are some issues to be resolved in order to take full advantage of its capabilities, such as the policy of application licensing and the integration into the applications of the capability to execute portions of code remotely.

The case study mentioned above shows the economy resulting from the use of cloud using a "private cloud". This benefit gets even greater if "public cloud" is used. That is, if a provider creates a similar service which he will provide to more than one company, in a pay-per-use basis. In this case obvious factors that reduce the cost are that the client-company will no longer need IT specialists, while this pay-per-use policy provides additional economy. Additionally, the provider can offer more applications to the end user.

The feasibility of a "public cloud" CAD-oriented service therefore must be examined, in order to reveal the additional benefits that it will provide to the end customers.

References

[1] Xu X. From cloud computing to cloud manufacturing. Robotics Comput-Integr Manuf 2012;28(1):75–86.

[2] Wu Dazhong, Rosen David W, Wang Lihui, Schaefer Dirk. Cloud-based design and manufacturing: a new paradigm in digital manufacturing and design innovation. Comput Aided Des 2014. http://dx.doi.org/10.1016/j.cad.2014.07.00.

[3] Helo P, Suorsa M, Hao Y, Anussornnitisarn P. Toward a cloud-based manufacturing execution system for distributed manufacturing. Comput Ind 2014;65(4):646–56.

[4] Laili Y, Tao F, Zhang L, Cheng Y, Luo Y, Sarker BR. A Ranking Chaos Algorithm for dual scheduling of cloud service and computing resource in private cloud. Comput Ind 2013;64(4):448–63.

[5] Andreadis G, Drossos A. A cloud based framework for automated cad design. Int J Mod Manuf Technol 2013;5(2):15–20.

[6] Andreadis G, Bouzakis K-D, Stamos K. Cloud-based CAD design. In: 4th international conference on manufacturing engineering, Thessaloniki; 2011. p. 357–66.

[7] Mezgár I. Role of trust in networked production systems. Annu Rev Control 2003;27(2):247–54.