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Evolution of Data Centre Networks and Design Specifications of MDCs

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ABSTRACT: Cloud computing is the next big future in computing. Cloud computing is not only related to Grid Computing but also to Utility computing as well as Cluster computing. The huge amount of data brings many challenges on the management, transportation and processing IT infrastructures. However, how to build a good data centre remains an open challenge. Concurrently, the architecture design, which significantly affects the total performance. This paper surveys advances in data centre Architectures and some popular design principles for today's data centre network architectures. Data centres are preassembled in a factory are often described with terms like prefabricated, containerized, modularized, mobile, portable, self-contained houses contains huge amount of all the types of resources required for computing environment and more. Shipping-container-based data centres have been introduced as building blocks for constructing mega-data centres.

KEYWORDS: Cloud Computing, Modular Data Centres, Containers, DC Architectures, Prefabricated Modular DC .

I. INTRODUCTION

Cloud Computing is a combination of Distributed Computing and Parallel Computing. It is a computing platform for sharing resources that include software's, business process, infrastructures and applications using the technology of virtualization. Companies offering these computing services are called Cloud Service Providers (Google, Microsoft, Amazon etc.) and typically charge for cloud computing services based on usage, similar to how you are billed for water or electricity at home. An example of a Cloud computing provider is Google's Gmail. This technology has many benefits, such as better hardware management, since all the computers are the same and run the same hardware (Virtualization). It also provides better and easier management of data, since all the data is located on a central server, so administrators can control the multi user access to the files.

The whole work that is related to cloud computing works in a virtual environment. To get the advantages of cloud user needs to only connect to the internet and after that user can easily use the powerful computing and capacity of storage [1]. Cloud computing has evolved over the time it has been majorly divided into 3 broad service categories: **Infrastructure as a Service (IAAS)**, **Platform as a Service (PAAS)** & **Software as a Service (SAAS)** [2].

Infrastructure as a Service (IAAS)

Infrastructure as a Service (IAAS) is a form of cloud computing that provides virtualized computing resources over the internet using Xen, VMware software Tools. In a IAAS model, a third party provider hosts hardware, software, servers, storage and other infrastructure components on the behalf of its users.

Platform as a Service (PAAS)

Platform as a Service (PAAS) is a cloud computing model that delivers applications over the internet. In a PAAS model, a cloud provider delivers hardware and software tools, usually those needed for application development, to its users as a service.

Software as a Service (SAAS)

Software as a Service (SAAS) is a software distribution model in which applications are hosted by a vendor or service provider and made available to customers over a network, typically the Internet.

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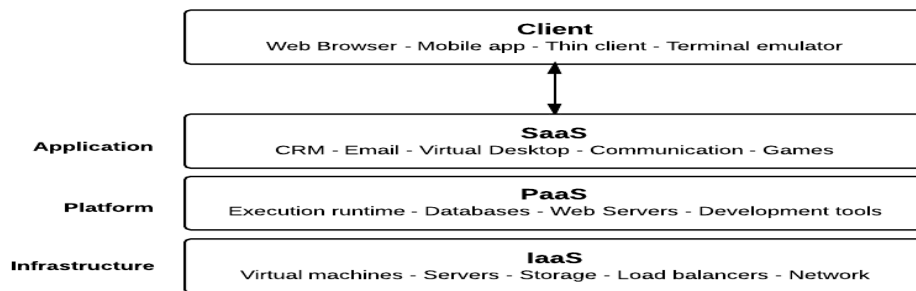


FIG. 1 CLOUD COMPUTING LAYER ARCHITECTURE

Some of the other service categories [3] which are more commonly classified as **anything as a Service (XAAS)** are:

Storage as a Service (SAAS)

Storage as a Service is a business model in which a large company rents space in their storage infrastructure to a smaller company or individual.

Communications as a Service (CAAS)

Communications as a Service (CAAS) is an outsourced enterprise communications solution that can be leased from a single vendor.

Network as a Service (NAAS)

Network as a Service (NAAS) is a framework that integrates current cloud computing offerings with direct, secure, client access to the network infrastructure.

Monitoring as a Service (MAAS)

Monitoring-as-a-service (MAAS) is a framework that facilitates the deployment of monitoring functionalities for various other services and applications within the cloud.

Data as a Service: The main idea of this type of service is to provide storage space to user, which is used to store large amounts of data and information.

Security as a Service: This type of service enables users to quickly deploy, allowing products to ensure the safe use of Web technologies security of electronic communications.

Nowadays, typical network architectures are a hierarchy of routers and switches. When the network size scales up and the hierarchy becomes deeper, more powerful (and much more expensive) routers and switches are needed. As the data centres further develop and expand the gap between the desired bandwidth and provisioning increases, though the hardware develops quickly as well. Thus, one of the major challenges in architecture design is how to achieve higher performance while keeping the cost low.

Design principles/issues

In this section, we present some design criteria and considerations of modern data centre designs.

Scalability: As the amount of data grows, we need more storage capacity to keep the data in the data centre. One typical way to increase storage is to add more components instead of replacing old ones.

Incremental scalability: In practice, instead of adding a huge number of servers at a time, we usually add a small number of storage hosts at a time. We expect minimal impact during the add-on on both the system operator and the system itself [6].

Cabling complexity: In traditional networks (e.g., homes and offices), the cabling complexity is simple. In data centre environments, however, cabling is a critical issue when tens of thousands of nodes are hosted.

Bisection bandwidth: Bisection bandwidth is defined as the bandwidth between two equal parts segmented from the original network using an arbitrary partition manner.

Aggregated throughput: The aggregate throughput measures the sum of the aggregated data rates when a network wide broadcast is conducted. It is also known as the system throughput.

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Oversubscription: Given a particular communication topology in a data centre network, its oversubscription is defined as the ratio of the maximal aggregate bandwidth among the end hosts in the worst case to the total bisection bandwidth [5].

Fault Tolerance: Hardware failures are common in large scale data centres, which make data centre networks suffer from poor reliability and low utilization [6].

Energy consumption: Recently, the power efficiency of data centre networks has become increasingly important. To save the energy consumption, we can use low-power CPUs and GPUs, equip more efficient power supplies, and apply water-cooling mechanisms.

Costs: The cost greatly affects the design decisions for building a large-scale data centre networks. We hope to leverage economic off-the-shelf hardware for large-scale network interconnection [4].

Fairness: For applications that farm work out to many workers and finish when the last worker finishes, such fairness can greatly improve overall performance in data centre networks.

Reliability: High reliability is one of the most essential criteria for designing data centre networks. In fact, a great waste of computing resources can be induced by an unreliable data centre networks that cause the operation of applications and services to fail.

Security: Security is also critical for the success of the data centre network services. Data exchanged between different nodes should be isolated from other unintended services to guarantee security.

Latency: In data centre networks, the delay incurred in the end systems or transmission between network nodes is called latency. For example, by reducing the international data transmission latency, the collocation cost can be reduced.

II. RELATED WORK

Existing DCN architectures: The data centre networks can be classified into three main classes namely,

Three-tier DCN: The legacy three-tier DCN architecture follows a multi-rooted tree based network topology composed of three layers of network switches, namely access, aggregate, and core layers.[9] The servers in the lowest layers are connected directly to one of the edge layer switches. The aggregate layer switches interconnects multiple access layer switches together. All of the aggregate layer switches are connected to each other by core layer switches. Core layer switches are also responsible for connecting the data centre to the Internet. The three-tier is the common network architecture used in data centres.[9] However, three-tier architecture is unable to handle the growing demand of cloud computing.[10]The higher layers of the three-tier DCN are highly oversubscribed.[10] Moreover, scalability is another major issue in three-tier DCN. Major problems faced by the three-tier architecture include, scalability, fault tolerance, energy efficiency, and cross-sectional bandwidth. The three-tier architecture uses enterprise-level network devices at the higher layers of topology that are very expensive and power hungry.[8]

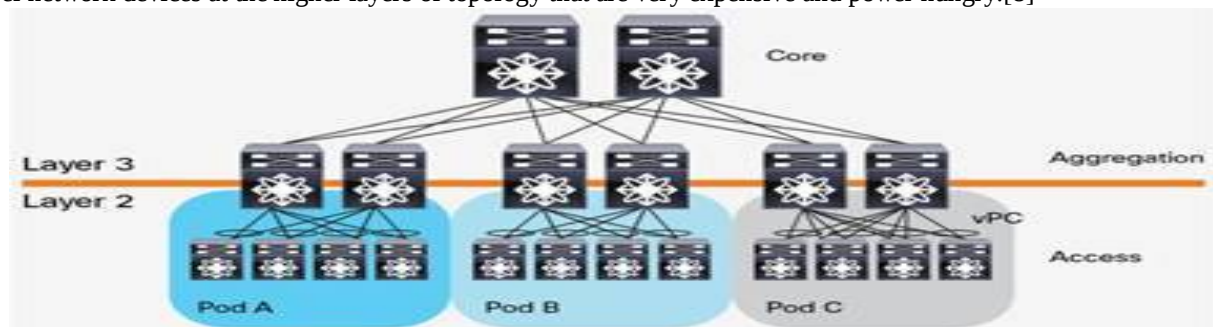


FIG. 2 THREE-TIER DCN

Direct network: Another option to make connections between the servers is by a direct network (also termed as “router-based network”). Direct networks directly connect servers to other servers in the network without any switch, routers, or network devices. Servers will serve both as a server and a network forwarder. Direct networks are often used to provide better scalability, fault tolerance, and high network capacities.

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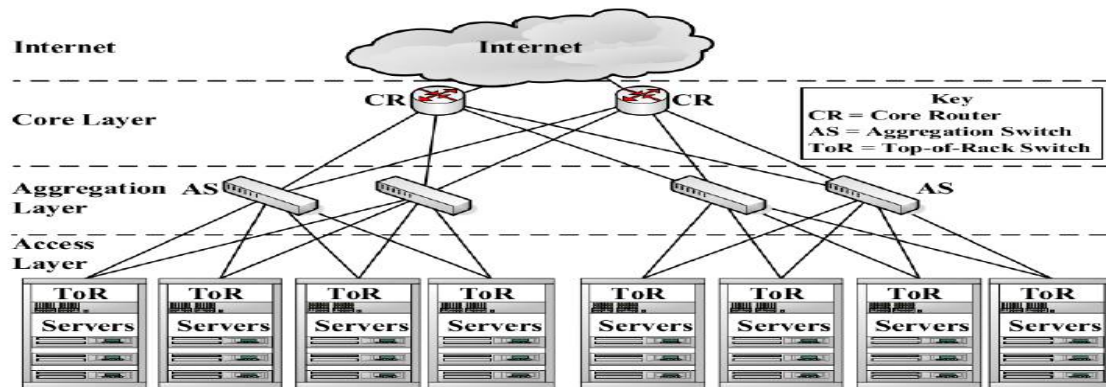


FIG. 3 DIRECT NETWORK

Hybrid network: A novel approach to interconnect servers and switches appears in the rising tide of employing optical circuit switches. Compared to packet switching, the optical circuit switching is superior in terms of its ultra-high bandwidth, low transmission loss, and low power consumption.

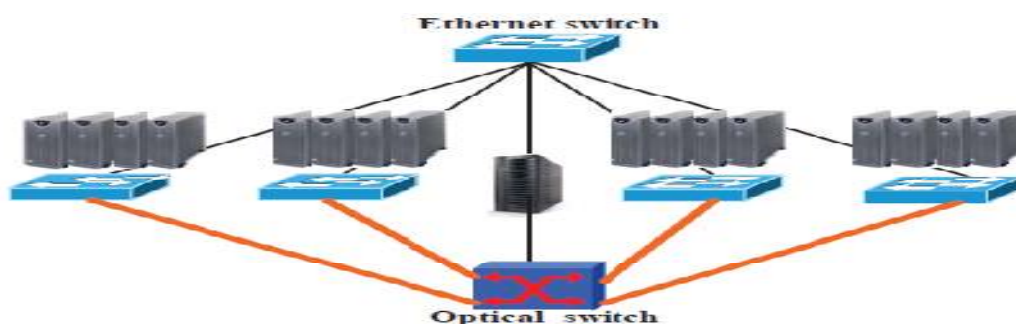


FIG. 4 HYBRID DCN

Fat tree DCN: Fat tree DCN architecture handles the oversubscription and cross section bandwidth problem faced by the legacy three-tier DCN architecture. Fat tree DCN employs commodity network switches based architecture using Clos topology.[3] The network elements in fat tree topology also follows hierarchical organization of network switches in access, aggregate, and core layers. However, the number of network switches is much larger than the three-tier DCN. The architecture is composed of k pods, where each pod contains, $(k/2)^2$ servers, $k/2$ access layer switches, and $k/2$ aggregate layer switches in the topology. The core layers contain $(k/2)^2$ core switches where each of the core switches is connected to one aggregate layer switch in each of the pods. The fat tree topology offers 1:1 oversubscription ratio and full bisection bandwidth.[7] The fat tree architecture uses a customized addressing scheme and routing algorithm. The scalability is one of the major issues in fat tree DCN architecture and maximum number of pods is equal to the number of ports in each switch.[10]

DCell: DCell is a server-centric hybrid DCN architecture where one server is directly connected to many other servers. A server in the DCell architecture is equipped with multiple Network Interface Cards (NICs). The DCell follows a recursively build hierarchy of cells. A cell0 is the basic unit and building block of DCell topology arranged in multiple levels, where a higher level cell contains multiple lower layer cells. The cell0 is building block of DCell topology, which contains n servers and one commodity network switch. The network switch is only used to connect the server within a cell0. A cell1 contain $k \cdot n + 1$ cell0 cells, and similarly a cell2 contains $k \cdot n + 1$ dcell1. The DCell is a highly

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scalable architecture where a four level DCell with only six servers in cell0 can accommodate around 3.26 million servers. Besides very high scalability, the DCell architecture depicts very high structural robustness. However, cross section bandwidth and network latency is a major issue in DCell DCN architecture.

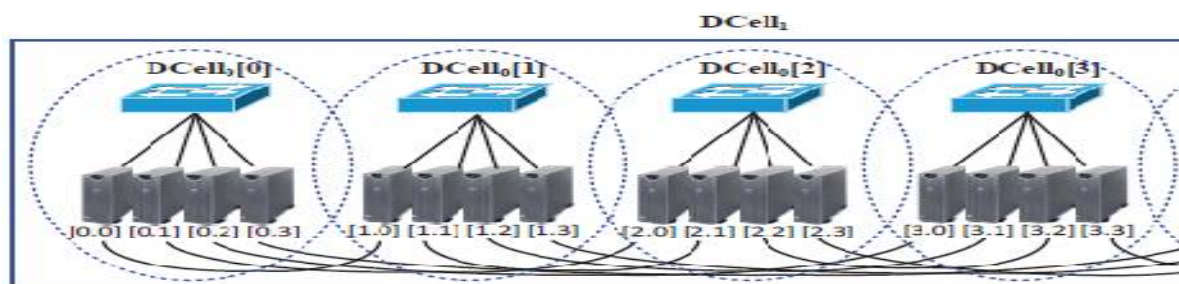


FIG. 5 DCELL DCN

III. PROPOSED WORK

This paper creates a framework for modular data centre architecture and describes the various ways that modularity can be implemented for data centre power, cooling, and space infrastructure and explains when the different approaches are appropriate and effective. Modularity is loosely defined as a technique that builds large systems out of smaller subsystems, where the subsystems have well defined rules for interfacing to each other. Modularity also suggests a simplified approach to installation or replacement, ideally with “plug in” of modular elements that require simplified commissioning.

Recent reports by Gartner reflect the growing realization that “The first two generations of data centre designs are no longer appropriate for current and future needs. New data centres should be perceived less as a static structure and more as an agile, living organism that evolves as the server and storage infrastructure changes.” In response, Gartner suggests operators should “Include flexible, modular, virtualized design principles in new data centre designs1.”

Problem	How modularity addresses the problem
Under-utilized capital investment resources	Modular approach allows infrastructure to be deployed as needed to meet demand, instead of being deployed up front.
Long design and installation cycle time	Modular data centers utilize systems that are pre-engineered and pre-manufactured, reducing design and installation time.
Quality	Using pre-engineered and pre-manufactured designs reduce defects.
Design for wrong density	Modular design allows decisions such as power density to be deferred until time of deployment, instead of being made years in advance.
Complex coding & configuration of management systems	Modular design allows re-use of standard management tools with more out-of-box functionality, and less one-of-a-kind programming.
Fault tolerance	Modular design typically includes the ability to add N+1 redundancy for fault tolerance and concurrent maintenance.
Standards compliance	Designs can be pre-verified for compliance for safety, energy efficiency, compatibility, security, etc avoiding the need for case-by-case evaluation and avoiding non-compliance surprises.
Simplified operator training	Training can be standardized and simplified since data center is not “one of a kind”.
Energy efficiency	The number one cause of data center inefficiency is overcapacity. Scalable modular data center design avoids this problem through rightsizing. Many other causes of inefficiency are also mitigated by pre-engineering and standardization.

TAB. 1HOW MODULARITY ADDRESS THE PROBLEMS IN DATA CENTRES

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Elements of modular architecture: 3 elements of modularity to describe data centre architecture

- Device modularity: devices are made up of modular components.
- Subsystem modularity: a functional block is made up of multiple devices or modules of the same type.
- Module Linkage: Relationships defined between the deployment of modules of different subsystems, determining how redundancies, capacities, and densities are achieved and scaled over time.

Device modularity: It is important to distinguish between modularity as applied to data centre architecture with modularity as applied to devices used within a data centre. There has been a long term trend toward modularity in all of the devices used in data centres including servers, storage devices, networking equipment, and UPS systems. The use of these modular devices can be an important element of modular data centre architecture. Examples of device modularity include modular UPSs and modular PDUs.

Subsystem modularity: Functional blocks (subsystems) within data centres, such as UPS, room air conditioning, and chillers can be implemented as single monolithic units or as a number of devices (modules) working together to share the load. For example a 1MW UPS requirement can be satisfied by any of the following combinations of devices:

- a single 1 MW UPS • four 250 kW UPSs • ten 100 kW UPSs • one thousand 1 kW UPSs

The individual UPS devices may or may not have “device modularity”, but the UPS subsystem is considered to be modular if it is comprised of multiple UPS devices.

Three major drivers of subsystem modularity are fault tolerance, concurrent maintenance, and logistics.

Fault tolerance is provided when the subsystem can survive the failure of one of the modules without interruption of the load. **Concurrent maintenance** is the related situation where a module can be taken off line for testing or maintenance without interruption of the load. **Logistics** of moving devices within a facility makes it highly beneficial when an individual module is small enough to be moved via a passenger elevator, shipped via an enclosed truck, and moved through doorways and over interior flooring surfaces without difficulty.

Module linkage: To deploy a unit of IT requires a combination of physical space, power, cooling, connectivity, fire suppression, and lighting. Therefore, the linkage of modularity across subsystem types within the data centre is a key concept in modular data centre architecture. In principle, a complete set of balanced and integrated subsystems could be deployed as a standard unit of modular data centre capacity. This would clearly be modular data centre architecture.

As an example of module linkage, consider the deployment of equipment racks and rack power strips. In this simple case we can define a 1 for 1 deployment. Now consider the deployment of PDUs and racks. In this case we might define a rule linking 1 PDU to every 20 racks. We could continue defining relationships such as 1 generator for every 500 racks, one Specification of Modular Data Centre Architecture Schneider Electric – Data Centre Science Centre Rev 2 6 CRAH for every 40 racks, one data acquisition system for every 200 racks, etc. We refer to rules relating these deployments as “linkages” of the modularity of the different subsystems.

Types of prefabricated modular data centres, defines and compares their key attributes: The three attributes that, together, define the majority of prefabricated modular data centres.



FIG.6THREE ATTRIBUTES OF DATA CENTRE

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1. Functional block

1.1. Power: A prefabricated power module is designed to provide bulk power to the data centre. The typical subsystems within a power facility module are switchgear / switchboards, ATS, UPSs with batteries, transformers, and panel boards. In addition, support systems such as lighting, security, cooling may exist in the module for enclosed form factors. Standby generators are generally a separate module that can be integrated with the power module.



FIG. 7 POWER

1.2. Cooling: Today's data centres use a range of cooling architectures to support the IT space, based on requirements for cost, efficiency, reliability, etc. The physical location (climate) of the data centre is also a big driver when determining the optimal approach.



FIG. 8 COOLING FUNCTION BLOCK

Cooling Modules: These units house modular **air-cooled chillers**, pumps with variable frequency drives (VFDs), a fluid storage tank, monitoring software, sensors and physical security cameras and can support up to a 500 kW capacity per container. A modular indirect evaporative cooling module is designed to live outside the data centre and can automatically switch between two forms of economized cooling. **Direct air module** brings in hot IT air in from the data centre through the modules' electronically commutated fans. This air is then passed through internal channels of the indirect evaporative cooler (IEC). While this is happening, cool ambient air is blown across the heat exchanger absorbing the heat energy of the IT air without actually mixing. After the IT air is cooled, it leaves the IEC and passes through the evaporator coil and returns to the data centre. In **Indirect air module** When ambient temperatures can't support an air-to-air heat exchange, economized cooling occurs through indirect evaporative cooling which removes heat from the IT air by evaporating water on the outside of the heat exchanger channels. The unit prevents the outside air from coming in contact with the data centre air, regardless of which cooling mode is used (air-to air or indirect evaporative).

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Chiller plant module	DX plant module	Indirect air module	Direct air module
• Air cooled chiller • Pumps / drives • Storage tank • Dry cooler / evaporative cooler	• Air cooled condenser or dry cooler • Pump package	• Air-to-air heat exchanger • Evaporative cooling • DX backup • Fans • Ducts	• Air filters • Evaporative cooling • DX backup • Fans • Ducts

TAB. 2 COOLING MODULES

1.3. IT Space: A prefabricated IT space is one that houses the IT equipment. It also houses the support infrastructure to distribute power and air to those systems, as well as provides a suitable work environment for the IT staff that must operate the space. Typically, such a module incorporates the following subsystems: • IT racks to hold the IT equipment • Power distribution units (PDUs) • Rack PDUs • Air distribution system (CRAHs, CRACs, air ducts, depending on architecture) • Humidification / dehumidification system • Cabling infrastructure / cable management • Fire detection / protection • Lights • Security systems.

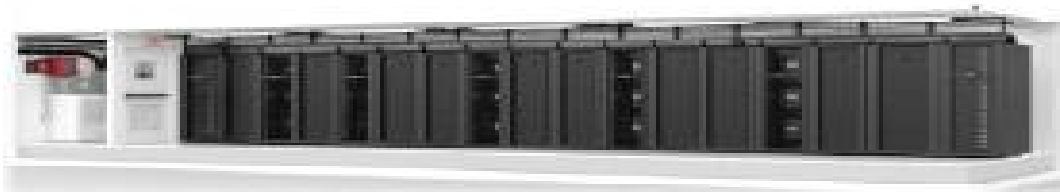


FIG. 9 IT SPACE

2. Form factor: meaning the type of structure, the size, and shape.

2.1. ISO container: ISO containers are standardized re-usable steel shipping enclosures, designed for safe, efficient, and secure storage and movement of materials from one form of transportation to another (i.e. ship to rail to truck). Standard footprints of these containers for use as data centre modules are: 20 ft x 8 ft (6.10 m x 2.44 m) and 40 ft x 8 ft (12.2 m x 2.44 m). The 20 ft (6.10 m) containers come in a standard height of 8 ft 6 in (2.591 m), and the 40 ft (12.2 m) containers come in either the standard height of 8 ft 6 in (2.591 m) or the "high bay" height of 9 ft 6 in (2.896 m).

	Location	Placement	Transportation
ISO container	Generally, outdoors	Mount on concrete pad or other foundation	Standard dimensions; from ship to rail to truck
Enclosure	May be placed indoors or outdoors, depending on weather rating & application	May ship in parts that require assembly onsite; Mount on concrete pad or other foundation	Shipping preparations may be required if in parts; Delivery may require permits, escorts depending on width
Skid-mounted	Generally, indoors	Often placed directly on room floor	Shipping preparations required; Delivery may require permits, escorts depending on width

TAB. 3 FORM FACTORS

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2.2. Enclosure: Another form factor, “enclosure”, is less standard in terms of its dimensions, and therefore does not necessarily meet specific shipping standards like the ISO containers. Enclosures are also commonly referred to as shells, metal houses, and pods.

2.3. Skid-mounted: “A skid mount is a method of distributing and storing machinery where the machinery at point of manufacture is permanently mounted in a frame or onto rails or a metal pallet. The equipment can then be easily and securely transported as and used as a unit.



FIG. 10 SKID-MOUNTED

3. Configuration

There are several ways the functional blocks can be implemented in a data centre. These approaches fall under three main categories:

- Semi-prefabricated – A data centre comprised of a combination of prefabricated functional blocks and traditional “stick built” systems.

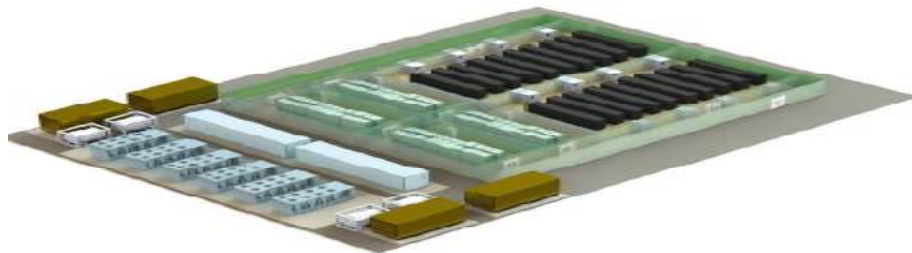


FIG. 11 SEMI-PREFABRICATED

- Fully prefabricated – A data centre comprised completely of prefabricated IT, power, and cooling modules.

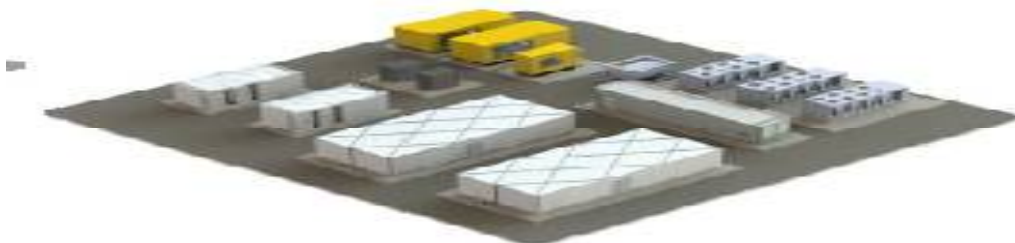


FIG. 12 FULLY PREFABRICATED

- All-in-one – A data centre that is self-contained in a single enclosure, with IT, power, and cooling systems.

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FIG. 13 ALL-IN-ONE

IV. CONCLUSION

Initially this paper defines what is meant by modular data centre architecture, so that operators, engineering firms, construction firms, and suppliers can begin to have productive conversations about modular data centre design using a common language. This paper finally proposing the optimal configuration, including the right functional blocks and form factors depends on the application and specific business requirements. But in most of the cases, a fully prefabricated data centre is the best approach, but a semi-prefabricated approach with a mix of prefabricated modules and traditional systems is best. Understanding the limitations and benefits of each form factor helps ensure the optimal approach is selected.

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