

POEMA: a Personal Cloud for Inclusive Education

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Abstract. The COVID-19 pandemic has evolved the way that education takes place. Distant or hybrid learning has confirmed the importance of cloud computing and network infrastructure for maintaining education activities in this situation. However, lessons learned from these experiences also show the problems of education exclusion and digital infrastructure limitations. In this paper, we analyze these two problems and propose a solution named POEMA, a Personal Cloud for inclusive education based on the cloud continuum concepts and beyond with explicit consideration of inclusiveness workloads by design. Likewise we propose an Inclusiveness Education Key Value Indicator (KVI) definition compatible with the 6G Key Value Indicator concept of Hexa-X.

Keywords. cloud continuum, cloud computing, edge computing, inclusive education, 5G/6G, personal cloud, key value indicator, inclusiveness KVI

1 Introduction

COVID-19 pandemic outbreaks accelerated the digital revolution. Telecommunications operators' role has been shown to be essential for the continuity of educational and economic activities¹. Most worldwide governments have closed schools during the COVID-19 pandemic [1]. Responses to the outbreaks in the education domain have been heterogeneous both on solutions to ensure continuity of learning and on the modularity of applied restrictions and the adopted systems, either

for full-time distance learning or to ensure continuity of education with a blended learning mode, mixing distance learning with degraded face-to-face learning [2].

As Custers [3] proposes, it is necessary to consider the new fundamental rights which would have to create in the digital age and reflect upon the rights that would have to be extended. In particular, he suggests introducing the right to Internet access, which would be strongly correlated to the evolution from the right to education² through digital education right, focused on reducing the digital divide and digital illiteracy.

Our research should be seen from this perspective of evolution from the right to education through the right to digital education centered on the impacts of telecommunication infrastructures on these rights, especially on digital inclusion. We would analyze its impact to model the open and flexible Information and Communication Technology (ICT) infrastructures that will sculpt the digital twins of schools of tomorrow in order to propose an open, inclusive, intelligent, and sustainable solution tailored to the education domain. We aim mainly at the context that requires substantially modifying the practice of learning, traditionally taught in a face-to-face manner and a dedicated building like the COVID-19 pandemic context.

Regarding the worldwide educational responses to the COVID-19 pandemic, experiences on teaching continuity based on distance learning reported from several countries highlight the importance of ICT infrastructures as a guarantee of reliable networks to simultaneously provide millions of users with smooth online learning, as well as the necessity of collaboration among different sectors as an enabler of inclusive access to education in emergency contexts [2]. Likewise,

¹The Impact of COVID-19 on the Global Telecommunications Industry. 2020. URL: https://www.ifc.org/wps/wcm/connect/Industry_EXT_Content/IFC_External_Corporate_Site/Infrastructure/Resources/covid-19+impact+on+the+global+telecommunications+industry.

²Le Droit de l'enfant à l'éducation; 1979 - 188684freo.pdf. URL: <https://unesdoc.unesco.org/ark:/48223/pf0000188684>.

unequal access to this infrastructure at home was a major challenge for most education systems, amplified by the electricity concerns in lower-income territories. In order to ensure access to education, many online learning solutions were adopted. Globally, a national online learning platform was used by 75% education systems. This percentage decreases through 62% in lower-middle income territories[4].

We were wondering what is the impact of network infrastructure currently used in education on learning and inclusive education and how to build a cloud continuum infrastructure at the lowest cost for learning and inclusive education depending on the context (out-of-coverage areas, rural areas, border areas, COVID-19 contexts, and post-COVID-19 contexts). In the same way, we also wonder how to use data mining techniques in a cloud continuum infrastructure as an education-inclusive vector applied to existing use cases and the new use cases that will emerge with 5G/6G technology.

To address the education infrastructure concerns, we propose an open cloud continuum infrastructure for inclusive education based on the new concept of the personal cloud, Personal Open Education Mobile Appliance (POEMA), extended beyond the edge of the network through the user devices (laptop, tablet, mobile phone, or IoT devices). In addition, following the 6G Key Value Indicator definition (KVI) as defined by the 6G European initiative, Hexa-X [5], we propose a new Inclusiveness Education KVI.

The remainder of this paper is organized as follows. Section 2 introduces the cloud continuum infrastructures background. Section 3 provides a overview of related work. Section 4 presents the POEMA architecture. Finally, we conclude and present the future directions in Section 5.

2 Cloud Continuum Infrastructures Background

Since the 60s, the evolution of computing paradigms has been characterized by alternating between paradigm waves of centralized computation and paradigm waves of distributed computation. In the 2000s, a paradigm of centralized computation named cloud computing emerged; this paradigm has been followed by its distributed alternative, the edge computing paradigm, to converge below in the cloud continuum or edge continuum [6, 7]. We will address the paradigms conforming Everything-as-a-service (XaaS) continuum, meaning the different services proposed to manage computing, storage, or networks, and what are the advantages and the limitations that present depending on their context. Finally, we will present a thriving approach, WebAssembly on the server side, which we find extremely promising for the new challenges of the cloud continuum and potentially

relevant for the new challenges of the education vertical.

The concept of cloud has been widely diffused. The amateurs and even the users without any computer skills have embraced it through the confluence of smartphone popularization and the rise of free online storage offers to data synchronizing in an ultra-connected and multi-device society. From a formal point of view, cloud computing consists of sharing a cloud provider's physical and virtual resources among multiple customers based on a multi-tenant architecture scalable on demand. These resources may be, for instance, computing, storage, or bandwidth [8]. The fundamental characteristics of cloud computing are on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service [9, 10]. All these features generate the illusion of unlimited capacity for the customers.

Cloud computing is the technical response to a globalized society that pushes us to consume more remotely than nearby. On the one hand, this consumption of computing resources all over the planet, all these data transiting by inter-continental networks, raises many societal questions about privacy, sovereignty, sustainability, and digital inclusion; on the other hand, cloud computing does not allow to address some use cases like those in the Internet of Things (IoT) field [11]. Regarding the education vertical, the COVID-19 pandemic fostered the emergence of new online educational models, revealing the limits of cloud computing to respond to a large number of simultaneous requests with reasonable latency times. For these reasons, we find it relevant to contextualize our research on the continuum of the cloud, edge, and beyond [12].

2.1 The Cloud Computing paradigms

There are many stakeholders in the industry gathered around cloud continuum challenges, of which Cloud Native Computing Foundation (CNCF) and Linux Foundation Edge (LF Edge) [13, 14]. Both of them are hosted by the Linux Foundation (LF) [15].

The leading actor in the cloud continuum is the CNCF, whose principal objective is to make cloud-native computing ubiquitous. Cloud-native technologies like containers or mesh services foster the observability and resilience of the system it implements.

The most popular CNCF project is Kubernetes [16], an open-source system for automating deployment, scaling, and managing containerized applications. We are interested in lightweight Kubernetes distributions like K3S or MicroK8S, which would be more relevant for the network edge[17, 18, 19].

Regarding the concept of edge computing, many definitions and nomenclatures exist in the literature (edge, fog, cloudlet) [20]. This paradigm addresses workloads with reduced latency, mobility scenarios, and critical-time response applications [11]. LF Edge

proposes a formal taxonomy, which is being adopted by the industry. Via this taxonomy, edge computing is presented as a continuum that extends from central data centers hosting cloud servers through edge devices located on the user side while traversing edge servers located on the telecommunications operator side.

2.2 The Serverless/FaaS paradigm

Cloud providers offer customers different models of services to manage the infrastructure where their applications will be deployed. In recent years, the dominant cloud computing service has been Infrastructure-as-a-Service (IaaS) [21]. This service is used, for example, by the public clouds of Web giants such as Amazon Web Services (AWS), Google App Engine (GCE) or Microsoft Azure. On the Open Source side, Open-Stack [22] is the most famous platform based on an IaaS model; it allows the creation of public and private clouds. The explosive extension of Kubernetes has oriented the market from the Infrastructure-as-a-Service (IaaS), the dominant model last years, to the Container-as-a-Service (CaaS), both of which present limitations regarding edge computing workloads. The serverless or Function-as-a-Service(FaaS) approach allows for addressing this point. Existing serverless/FaaS solutions, some are based on classic virtual machines (VMs); others on the micro-virtual machines (microVMs), like the AWS Lambda Functions; other on Docker containers like the IBM Cloud Functions; or still on a compromise between several approaches of VMs and containers depending on the context, such as Microsoft Azure Functions or Google Cloud Functions. However, existing FaaS solutions based on containers or Virtual Machine (VM) approaches do not take advantage of the benefits of this model [23].

The new FaaS stacks would be designed to avoid these limits improving performance and scalability, the startup time, and the footprint for every function call. Additionally, it could support a more accurate billing model [21].

2.3 WebAssembly on the server side

In order to lighten the execution environment to run the functions characterizing a FaaS platform, the literature proposes flicker virtualization technologies. Among these technologies, WebAssembly (Wasm) traverses the mirror of the Web through the server side, offering remarkable advantages for web applications[24]. Solomon Hykes, Docker's founder, says that if WebAssembly had existed in 2008, Docker would not have been created³.

The WebAssembly and WebAssembly System Interface (WASI) [25] standards have been developed by

³Solomon Hykes sur Twitter. Twitter. URL: <https://twitter.com/solomonstre/status/1111004913222324225>.

the Bytecode Alliance [26]. The objective is to develop new runtimes and language toolchains that provide security, efficiency, modularity, and portability based on a fine-grained sandboxing approach, improving the software composability and cross-device feature in the future. It transposes hence ubiquity in interoperability of the Web through the pervasive computing world. With near-native performance, the literature shows that Wasm improves the cold start time compared to other runtimes like Docker on different public cloud platforms. However, despite all hope for Wasm, it presents several limits. In effect, it is necessary to consolidate features such as the network and the multithreading management tools. Otherwise, to fully benefit from the LLVM chain, the support for programming languages must be completed [21, 27].

2.4 The 6G Key Value Indicators

The fundamental principles of 6G, still in an inchoative state, shift the center of gravity of cellular networks towards a dual vision composed of technology and society. Hexa-X, the most significant 6G European initiative, means digital inclusion as three 6G key value with sustainability and reliability. Its vision of 6G includes the concept of the Key Value Indicator (KVI), which aggregates evolution of the classic notion of Performance Indicator (KPI) like the connection density with the new indicators as the integrated intelligence or the artificial intelligence/machine learning (AI/ML) for the optimization of network operations. Regarding the KVI, Hexa-X underlines the difficulty of measuring and quantifying societal values and the perceived performance value. To quantify the KVI is suggested to use softer indicators. It would be linked, for example, to a specific use case or an emergent trend that would allow affecting a relative weight to a given KPI, and their values would be considered from a global point of view. Regarding the perceived performance and standardizing these subjective perceptions set modeled by the personal or collective environments of each individual, the most suitable is to be based on the Sustainable Development Goals (SDGs) of the United Nations Organisation (UNO)⁴, that is the most open, and inclusive toolset that exists. For education use cases, SDG 4, piloted by UNESCO⁵, is focused on ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all.

3 Related work

Concerning research in cloud continuum infrastructures for education, we made an exploratory phase

⁴THE 17 GOALS | Sustainable Development. URL: <https://sdgs.un.org/goals>.

⁵Leading SDG 4 - Education 2030 | UNESCO. URL: <https://www.unesco.org/en/education2030-sdg4>.

to provide an overview of works studying the transition from the centralized cloud computing model to the edge computing model and their integration with artificial intelligence technologies (AI), especially the techniques emerging from the machine learning (ML) subfield. AI combined with other technologies like blockchain or genetic algorithms is very promising for research in education infrastructures.

Several studies present a cloud continuum infrastructure for education based on the edge computing paradigm, including an Internet of Things (IoT) layer. As described in the Introduction section, the centralized cloud computing approach presents some limitations concerning IoT devices, especially for latency. In [28], the authors highlight the need for cloud-edge infrastructures to use industry 4.0 technologies to improve education infrastructures. They propose an education framework based on an IoT edge infrastructure, describe some limitations of these approaches, and make some proposals to address them. These limitations are the security concerns like authentication, manual configurations, and privacy protection; the network management across heterogeneous devices; the time for data aggregation; the lack of expertise and adequate infrastructure of educational institutions.

Security concerns could be addressed with blockchain technology, an up-and-coming technology for the development of smart campuses which brings cyber-security and redundancy to the processes and data managed [29].

Educational data or infrastructure data from the IoT layer were exploited with AI/ML techniques. In an experience carried out in Pakistan, [30] a cost-effective infrastructure based on Convolutional Neural Networks (CNN) was implemented to build a digital twin framework for performance monitoring of teachers and attendance monitoring of students and teachers without human intervention. Moreover, the authors consider to include blockchain technology in their future works to provide a more secure framework.

In [31], in addition to the IoT layer, some functions of education governance are available for parents and students through mobile internet. A total of 91.3 % of parents gave positive feedback on this intelligent home control system. Techniques based on genetic algorithms were proposed in two of explored works. In [32] a central cloud approach was used complemented with an edge node adaptive data type sensing mechanism based on counting bloom filter, optimized using genetic algorithms techniques and implemented applying the blockchain agricultural products trading process. Additionally, in [12] an offloading mechanism also based on genetic algorithms was presented in order to minimize the computing delay of terminal tasks of an edge infrastructure for preschool education.

To the best of our knowledge, POEMA is the first proposition in terms of personal cloud for education. There exist other solutions for edge cloud such as the

mesh router of Green Communications [33]. Applications such as education applications can be embeded into these mesh routers. However, the main objective of mesh routers is to provide a network infrastructure with distributed embedded applications. They don't have the cloud continuum feature based on serverless technology and a specific objective of personal cloud dedicated to inclusive education as our proposed solution.

4 The POEMA Architecture

4.1 Our Personal Cloud concept: POEMA

The United Nations Educational, Scientific and Cultural Organization (UNESCO) and the European Agency for Special Needs and Inclusive Education (EASNIE) have formulated several recommendations. In 2019, UNESCO adopted the first international recommendation regarding the field of openly licensed educational materials and technologies in education [34] and defines the concept of Open Educational Resources (OER)⁶. It addresses all formal and informal education sector stakeholders, including ICT infrastructure providers or cloud providers. In 2021, EASNIE proposed several recommendations in the context of the COVID-19 pandemic, ensuring free and inclusive access to digital resources in all remote learning processes.

As discussed previously, the COVID-19 pandemic revealed the limits of infrastructures of education, increasing the digital divide: central cloud model presents limits for the uses cases of massive distance or hybrid learning like the COVID-19 or the future classroom technology with extended reality (xR), namely augmented reality (AR), virtual reality (VR) and mixed reality (MR).⁷ Some limits are the data sovereignty, enormous latency, energy consumption, or the commercial factors related to the traditional domain of telecommunications infrastructures based on vendor-locked hardware infrastructures [35]. Edge computing infrastructures partially address these concerns, but the education vertical needs more flexible, mobile, extensible, and resilient infrastructures in order to guarantee the continuity of education in planetary scenarios like the COVID-19 pandemic, natural disasters, or human migrations.

Taking into account the UNESCO and the EASNIE recommendations and in order to try to answer the research questions we described previously, we suggest

⁶This norm defines the concept of Open Educational Resources (OER) as "learning, teaching, and research materials in any format and medium that reside in the public domain or are under the copyright that has been released under an open license, that permits no-cost access, re-use, re-purpose, adaptation and redistribution by others."

⁷Arm Blueprint staff. *xR, AR, VR, MR: What's the Difference in Reality?* Arm Blueprint. URL: <https://www.arm.com/blogs/blueprint/xr-ar-vr-mr-difference>.

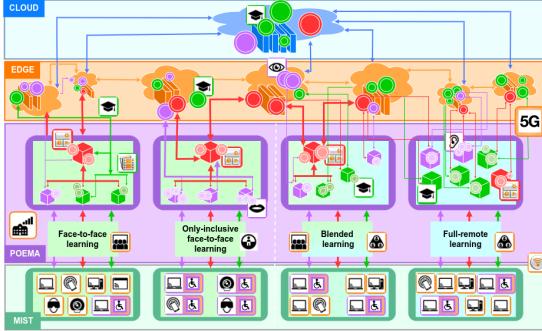


Figure 1: POEMA architecture

an extension of the notion of OER, at the moment focused on education contents, through the Open Educational Resources and Inclusive Infrastructures (OERII). It could provide open solutions for the digital inclusion challenges in education, especially for identified contexts with a critical inclusion fracture like the out-of-coverage areas, rural areas, border areas, and COVID-19 contexts. For this purpose, we propose a tiers architecture inclusive by design with the new concept of Personal Cloud named Personal Open Education Mobile Appliance (POEMA), mainly based on the FaaS paradigm and a new Inclusiveness Education KVI.⁸

POEMA is a new tier in the cloud continuum spectrum, which would be located beyond the edge tier, between the user device (tablet, laptop, and IoT devices) and the base station of the telecom provider or the access point. To begin with, we consider a scenario in which the POEMA nodes could connect to the telecom provider edge nodes only with 5G gNodeB.

In Fig. 1, we present a high-level vision of the POEMA architecture that we describe briefly below.

- **Cloud tier:** This tier is represented in a blue color range. It hosts the nodes of the central data centers. This tier addresses the traditional distance or hybrid learning education use cases.
- **Edge tier:** This tier is represented in an orange color range. It hosts the nodes of the edge data centers. This tier addresses sovereignty, latency, and energy consumption issues of traditional distance or hybrid learning education use cases.
- **POEMA tier:** This tier is represented in a purple color range. It hosts the nodes corresponding to POEMA devices. This tier provides flexibility and extensibility required by the inclusion uses cases and guarantees the continuity of education. Its flexibility and extensibility could contribute to enhancing inclusion with more personalized education infrastructures and also to implement easily not traditional education use cases like flipped classrooms, outdoor classrooms, or gamified classrooms.

⁸The word "poema" means poem in Spanish and proceeds from the Latin *poēma*

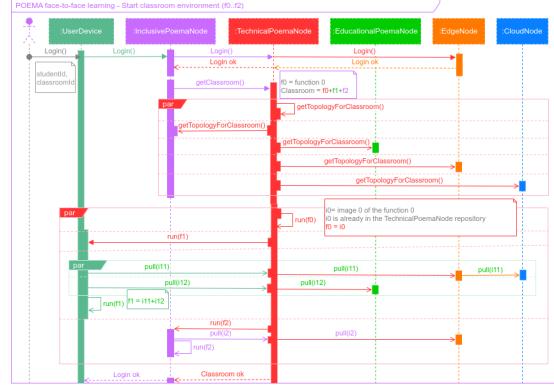


Figure 2: POEMA sequence diagram

- **Mist tier:** This tier is represented in a green color range. It hosts the nodes of the user devices.

In Fig. 2, we present a sequence diagram for the default face-to-face scenario.

POEMA workloads

- **POEMA technical functions:** The set of functions implementing technical actions like authentication, education environment build, or orchestration. This set is represented in a red color range.
- **POEMA educational functions (POEMA OER functions):** The set of educational functions which compose the OERs, as an open-source video conferencing application, for instance, a BigBlueButton alternative tool mainly based on a FaaS model. This set is represented in a green color range.
- **POEMA inclusiveness functions:** The set of functions implementing actions to improve the inclusiveness of the POEMA infrastructure. For instance, the functions related to simultaneous translation for face-to-face, blended, or full remote learning activities for refugees of different origins and studying in regular schools. This set is represented in a purple color range.

4.2 Our new Inclusiveness Education KVI

We propose a new Inclusiveness Education KVI, compatible with the 6G KVI definition proposed by Hexa-X. This soft inclusiveness indicator will be computed with the data measured on specific inclusiveness workloads identified in our system as POEMA inclusiveness functions. Our first use case is the French National Education infrastructure, and we are analyzing public datasets of this use case available on the French National Education open data repository [36]. This repository provides open data sets with general information about the schooled population and digital inclusion statistics like the ETIC survey. The ETIC survey

collected yearly data from all public schools in France regarding digital equipment, infrastructures, and services that permit us to compute indirect soft partial inclusiveness indicators between different contexts, such as rural or urban. Additionally, the survey provides inclusion data, for example, if a school has pedagogical material available to students supplied for ASH (Adaptation, Schooling, Handicap) and the number of them. These data permit us to compute directly soft partial to build a heuristic to calculate the initial weight of the inclusiveness workload functions in a given school or region. Thus, we have to define a global inclusiveness KVI composed of partials inclusiveness KVI as cited before and other 5G/6G KPIs as area traffic capacity or energy efficiency.

5 Conclusions and Future Work

Nowadays, millions of learners study online from their homes. During the COVID-19 pandemic, education was strongly impacted, shifting from full-time to online learning when possible, increasing the digital divide. The success factors of the abrupt commutation from face-to-face education systems to remote education systems on a planetary scale were the individual efforts of digitalizing their infrastructures from some countries or schools before the pandemic, hence the help from leading tech companies. This health crisis has revealed difficulties in accessing the Internet and the lack of digital skills in the educational community. Education ICT infrastructures for remote or blended learning are based on central cloud computing paradigms that present limitations regarding data sovereignty, sustainability, or vendor-locking constraints. The edge continuum infrastructures provide partial responses for these issues. However, the education vertical need more flexible, mobile, extensible, and resilient infrastructures to guarantee the continuity of education in scenarios like the COVID-19 pandemic and implement future education scenarios that will emerge with 5G/6G technologies.

To address inclusion challenges, this paper presents the new concept of POEMA, based on a FaaS model that proposes a new tier for a flexible cloud continuum infrastructure for inclusive education with explicit consideration of inclusiveness workloads by design. This architecture would be an extension of the OER conceptual framework for inclusive education infrastructures (OERII), including a new Inclusiveness Education KVI compatible with the 6G KVI notion described by Hexa-X.

In future work, we plan to implement a simulator based on existing cloud continuum simulators like CloudSim Plus in order to validate our system. We will implement an inclusive algorithm to schedule the educational workloads to optimize the inclusiveness of our OERII architecture, maximizing our Inclusiveness Education KVI. We would like to create many simula-

tions crossing basic education use cases (face-to-face learning, blended and full-remote learning) with several specific contexts such as rural versus urban, pre-COVID-19 versus COVID-19 context, post-COVID-19 versus Metaverse and Omniverse contexts. Finally, we will also contemplate creating end-to-end testbed from the public cloud to user devices implementing POEMA level with low-cost devices to validate partial aspects of this POEMA architecture in an almost-real context; for instance, we may deploy some workloads on Wasm runtimes.

References

- [1] *Education: An Unprecedented Crisis* | UNESCO. 2022. URL: <https://courier.unesco.org/en/articles/education-unprecedented-crisis>.
- [2] Huang, R.H., Liu, D.J., Tlili, A., Yang, J.F., Wang, H.H., et al. *Handbook on Facilitating Flexible Learning During Educational Disruption: The Chinese Experience in Maintaining Undisrupted Learning in COVID-19 Outbreak*. Smart Learning Institute of Beijing Normal University, 2020.
- [3] Bart Custers. “New Digital Rights: Imagining Additional Fundamental Rights for the Digital Era”. In: *Computer Law & Security Review* 44 (Apr. 1, 2022), p. 105636. ISSN: 0267-3649. DOI: [10.1016/j.clsr.2021.105636](https://doi.org/10.1016/j.clsr.2021.105636).
- [4] *National education responses to COVID-19: summary report of UNESCO’s online survey - UNESCO Bibliothèque Numérique*. United Nations Educational, Scientific and Cultural Organization, Paris, France, April, 2020. URL: <https://unesdoc.unesco.org/ark:/48223/pf0000373322>.
- [5] *Hexa-X H2020 5G-PPP project. Deliverable D1.2, Expanded 6G vision, use cases, and societal values*, URL: https://hexa-x.eu/wp-content/uploads/2023/01/Hexa-X_D5.1_full_version_v1.0.pdf.
- [6] Mahadev Satyanarayanan. “The Emergence of Edge Computing”. In: *Computer* 50.1 (Jan. 2017), pp. 30–39. ISSN: 0018-9162. DOI: [10.1109/MC.2017.9](https://doi.org/10.1109/MC.2017.9).
- [7] *State of the Edge Report 2021 - State of the Edge*. URL: <https://stateoftheedge.com/reports/state-of-the-edge-report-2021/>.
- [8] David Bernstein. “Containers and Cloud: From LXC to Docker to Kubernetes”. In: *IEEE Cloud Computing* 1.3 (Sept. 2014), pp. 81–84. ISSN: 2325-6095. DOI: [10.1109/MCC.2014.51](https://doi.org/10.1109/MCC.2014.51).

[9] Peter Mell and Tim Grance. *The NIST Definition of Cloud Computing*. DOI: 10.6028/NIST.SP.800-145. URL: <https://csrc.nist.gov/publications/detail/sp/800-145/final>.

[10] *Cloud computing | CNIL*. URL: <https://www.cnil.fr/fr/definition/cloud-computing>.

[11] Wazir Khan, Ejaz Ahmed, Saqib Hakak, Ibrar Yaqoob, and Arif Ahmed. *Edge computing: A survey*. Future Generation Computer Systems, Elsevier, Vol. 97, 2019.

[12] Xiaoxuan Duan. *Online preschool education optimization based on edge computing in the era of COVID-19*. Internet Technology Letters, Vol. 4, Issue 5, Wiley, September/October 2021.

[13] CNCF. URL: <https://www.cncf.io/>.

[14] *LF Edge: Building an Open Source Framework for the Edge*. LF Edge. URL: <https://www.lfedge.org/>.

[15] *Linux Foundation - Decentralized innovation, built with trust*. URL: <https://www.linuxfoundation.org>.

[16] *Kubernetes*. Kubernetes. URL: <https://kubernetes.io/>.

[17] *Small Kubernetes for your local experiments: k0s, MicroK8s, kind, k3s, and Minikube – Flant blog*. URL: <https://blog.flant.com/small-local-kubernetes-comparison/>.

[18] *K3s*. URL: <https://k3s.io.github.io/>.

[19] *MicroK8s - Zero-ops Kubernetes for developers, edge and IoT* | MicroK8s. microk8s.io. URL: <http://microk8s.io>.

[20] Alberto Ceselli, Marco Premoli, and Stefano Secci. “Mobile Edge Cloud Network Design Optimization”. In: *IEEE/ACM Transactions on Networking* PP (Jan. 2017). DOI: 10.1109/TNET.2017.2652850.

[21] Ju Long, Hung-Ying Tai, Shen-Ta Hsieh, and Michael Juntao Yuan. *A Lightweight Design for Serverless Function as a Service*. IEEE Software, Vol. 38, Issue 1, January/February 2021.

[22] *Open Source Cloud Computing Infrastructure*. OpenStack. URL: <https://www.openstack.org/>.

[23] Phani Kishore Gadepalli, Sean McBride, Gregor Peach, Ludmila Cherkasova, and Gabriel Parmer. *Sledge: a Serverless-first, Light-weight Wasm Runtime for the Edge*. 21st ACM International Middleware Conference (Middleware), Delft, Netherlands, December, 2020.

[24] Alfonso de la Rocha. *@adlrocha - Can WASM become the new Docker?* URL: <https://adlrocha.substack.com/p/adlrocha-can-wasm-become-the-new>.

[25] *WebAssembly*. URL: <https://webassembly.org/>.

[26] *Bytecode Alliance*. Bytecode Alliance. URL: <https://bytecodealliance.org/>.

[27] Philipp Gackstatter, Pantelis A. Frangoudis, and Schahram Dustdar. “Pushing Serverless to the Edge with WebAssembly Runtimes”. In: *2022 22nd IEEE International Symposium on Cluster, Cloud and Internet Computing (CCGrid)*. 2022 22nd IEEE International Symposium on Cluster, Cloud and Internet Computing (CCGrid), pp. 140–149.

[28] Shams Tabrez Siddiqui, Mohammad Rafeek Khan, Zeba Khan, Nadim Rana, Haneef Khan, and Md Imran Alam. “Significance of Internet-of-Things Edge and Fog Computing in Education Sector”. In: *2023 International Conference on Smart Computing and Application (ICSCA)*. 2023 International Conference on Smart Computing and Application (ICSCA). Feb. 2023, pp. 1–6. DOI: 10.1109/ICSCA57840.2023.10087582.

[29] Tiago M. Fernández-Caramés and Paula Fraga-Lamas. “Towards Next Generation Teaching, Learning, and Context-Aware Applications for Higher Education: A Review on Blockchain, IoT, Fog and Edge Computing Enabled Smart Campuses and Universities”. In: *Applied Sciences* (2076-3417) 9.21 (Nov. 2019), p. 4479. ISSN: 20763417. DOI: 10.3390/app9214479. URL: <https://search.ebscohost.com/login.aspx?direct=true&AuthType=sso&db=aps&AN=139691083&lang=fr&site=eds-live&custid=ns017062>.

[30] Saad Razzaq, Babar Shah, Farkhund Iqbal, Muhammad Ilyas, Fahad Maqbool, and Alvaro Rocha. “DeepClassRooms: A Deep Learning Based Digital Twin Framework for on-Campus Class Rooms”. In: *Neural Computing and Applications* 35.11 (Apr. 1, 2023), pp. 8017–8026. ISSN: 0941-0643. DOI: 10.1007/s00521-021-06754-5. URL: <https://search.ebscohost.com/login.aspx?direct=true&AuthType=sso&db=edssjs&AN=edssjs.E49BAA42&lang=fr&site=eds-live&custid=ns017062>.

[31] Yanhui Guo. “Application of Internet of Things Technology in Mobile Education of Smart Campus Culture and Etiquette”. In: *Journal of Sensors* (July 15, 2022), pp. 1–10. ISSN: 1687725X. DOI: 10.1155/2022/6321784. URL: <https://search.ebscohost.com/login.aspx?direct=true&AuthType=sso&db=aps&AN=158020099&lang=fr&site=eds-live&custid=ns017062>.

[32] Mei Liu, RuJin Zhou, Jing Dai, and XiaoLing Feng. “Analysis and Practice of Using Modern Information Technology for Classroom Teaching Mode Reform”. In: *Mobile Information Systems* (Aug. 5, 2022), pp. 1–8. ISSN: 1574017X. DOI: [10.1155/2022/2565735](https://doi.org/10.1155/2022/2565735). URL: <https://search.ebscohost.com/login.aspx?direct=true&AuthType=sso&db=aps&AN=158380443&lang=fr&site=eds-live&custid=ns017062>.

[33] *Green Communications – Internet-of-Edges (IoE)*. URL: <https://www.green-communications.fr/>.

[34] *Ressources éducatives libres (REL) accessibles: document d'information - UNESCO Bibliothèque Numérique*. URL: https://unesdoc.unesco.org/ark:/48223/pf0000380471_fre.

[35] Mehmet Akcin. *Council Post: Edge Of Sovereignty: Navigating Data Security And Compliance In Latin America's Evolving Tech Landscape*. Forbes. 2023. URL: <https://www.forbes.com/sites/forbestechcouncil/2023/04/26/edge-of-sovereignty-navigating-data-security-and-compliance-in-latin-americas-evolving-tech-landscape/>.

[36] *Explore — Éducation Nationale - Accueil*. URL: <https://data.education.gouv.fr/explore/?sort=modified>.