The European Landscape of High Performance Computing

Carmen-Elena CÎRNU, Alina STĂNESCU
National Institute for Research and Development in Informatics - ICI Bucharest
carmen.cirnu@ici.ro, alina.stanescu@ici.ro

Abstract: This article looks at High Performance Computing (HPC) as playing an essential role within European initiatives that are oriented toward the multifaceted growth of society. After offering a broad definition and presenting the state of the art of HPC, there will be highlighted some important general use cases of this particular technology that bring to light its strengths and valuable potential especially in the context of Industry 4.0. The article then focuses on very specific European HPC initiatives, zooming into the EuroHPC JU program and EuroCC project. The main activities of the Romanian National Center of Competence in HPC will also be described, thus ending the overview with a national view of the HPC landscape within the larger context.
Keywords: HPC, parallel processing, supercomputing, Industry 4.0, digital twin, artificial intelligence, big data.

INTRODUCTION

High Performance Computing (HPC) generally represents the technological ability to process data and perform complex calculations at very high speeds but there is no clear-cut or definitive definition of this concept. The common activities associated with this technology are related to supercomputer operations, problem solving and research as well as engineering design using computer modeling, simulations and analysis. One of the most widely known forms of HPC solutions is the supercomputer itself, within which a multitude of compute nodes are found, working together to complete one or several tasks. HPC relies on "parallel processing", which may be compared to having thousands of computers networked together, combining computational power and thus increasing the speed of any task completion. Accordingly, supercomputing is becoming an essential tool for understanding and responding to complex challenges and working to harness and transform them into innovation opportunities.

https://doi.org/10.54851/v4i2y202204

HPC USE CASES

HPC is useful at different levels - with respect to users, at the level of society (citizens) and with respect to domains, primarily at the level of science and industry. Regarding **citizens**, the beneficial applications are for example visible in *medicine*, in developing and targeting medical therapies for the individual needs and conditions of patients with severe illnesses such as cancer; testing and developing COVID-19 new treatments, as well as in understanding the generation and evolution of various diseases and their spreading patterns which can consequently lead to important preventive actions. HPC is also used in *cybersecurity*, especially for the protection of critical infrastructures which are becoming highly digitalized. Another benefit of HPC within society regards *weather prediction* and *climate change*.

It can be used in order to provide accurate simulations predicting the evolution of weather patterns, as well as important measurements about storms and floods.

Furthermore, there are various applications of HPC in **science**, ranging from fundamental physics (exploring the universe) to material sciences (developing new critical elements for the energy sector or the pharmaceutical one) and earth science (modelling phenomena at global level).

In **industry**, HPC promotes innovation and growth in sectors like aerospace, health, sustainable and green energy, automotive and others. By using supercomputing, they are becoming more productive and able to evolve to higher value services and products, at the same time reducing costs and increasing energy efficiency. Using HPC, engineers can quickly adjust designs, make changes within iterations of component development while designing and evaluating a product utilizing digital twins or simulation models. The concept of digital twin refers to the ability to virtually represent and optimize a real-life product or process. It is best described as the effortless integration of data between a physical and virtual machine in either direction (Fuller et al, 2020).

Due to the exponential technological advance, expressed by processing power, memory capacity and the multitude of developed applications, Industry 4.0 has been reached, translated as an industrial revolution marking the next decades. The development and large-scale use of cyber-physical systems will quickly evolve, and HPC will surely become fuel to its engine. HPC can shorten the time it takes to get a new product to market or assist a company innovate on designs. Because of these advantages, engineering simulation is now financially viable for a wider range of end customers across numerous industries and business sizes.

As it becomes clearer from its benefits and strengths, HPC solutions as an integral part of the emerging Industry 4.0. are used for a variety of purposes across multiple sectors (also as seen in Figure 1), for example in:

- **Study facilities/research laboratories.** Scientists use HPC to help them discover renewable energy sources, comprehend how the universe has evolved, forecast and monitor storms, and develop novel material. Computing is a tool as important as experimentation and theory in solving various scientific problems of the twenty-first century. The mission of the laboratory is to support computational science, in which interdisciplinary teams of scientists consider fundamental problems in science and engineering that require computation and have broad scientific and economic impacts;
- **Entertainment and media.** HPC is used in editing feature films, creating special effects, and streaming live events globally. From using high-resolution computer-generated imagery (CGI) and visual effects (VFX) to render lifelike scenes in seconds, to streaming content to audiences around the world in real time, to matching viewers with rich content, High Performance Computing (HPC) has long been used to speed media creation and delivery. Recently, artificial intelligence has started creating new ways for media and entertainment companies to accelerate time to market and save money while

offering new and improved experiences to increasingly specialized audiences.

- **Gas and oil.** HPC is utilized to increase production from already-existing wells and more precisely pinpoint where to dig new wells. It is also used to detect and accelerate deeper geological insights; hence improve the exploration and production processes. Nonetheless, HPC systems offer the required tools to help midstream pipeline operators to increase operational efficiency and compliance in many phases such as gas transportation, pipeline integrity management, and workforce management;
- **Machine learning and artificial intelligence (AI).** HPC is used to prevent financial fraud, offer self-directed technical assistance, train autonomous vehicles, and advance cancer detection methods. Conventionally, numerical analysis has formed the backbone of supercomputing for decades by applying mathematical models of first-principle physics to simulate the behavior of systems from subatomic to galactic scale. Recently, scientists have started experimenting with a relatively new approach to understand complex systems using machine learning (ML) predictive models, primarily Deep Neural Networks (DNN), trained by the virtually unlimited data sets produced from traditional analysis and direct observation. Initial results indicate that these „synthesis models" combining ML and traditional simulation, can improve accuracy, accelerate time to solution and significantly reduce costs;
- **Monetary services.** HPC is used to automate trading and monitor real-time stock trends. Going beyond the capabilities of a regular PC, HPC enables financial organisations to get access to information faster, run applications more efficiently, analyze data more quickly, and streamline processes;
- **Manufacturing:** HPC is used to design new products, simulate test scenarios, and make sure that parts are kept in stock so that production lines aren't held up. High Performance Computing can help manufacturers at every stage of product development and supply chain, from running advanced design simulations to automating processes and predicting maintenance issues;
- **Prevention and treatment:** In healthcare and life sciences area, HPC offers a wide range of benefits, including scalability and the ability to better manage diverse workloads. To offer only one single example, HPC is used to help develop cures for diseases like diabetes and cancer and to enable faster, more accurate patient diagnosis.

Fig. 1: *HPC areas of application (image source: Xilinx)*

In order to prevent production lines from being slowed down, HPC is used to design new products, simulate test situations, and ensure that parts are kept in stock. HPC is also utilized to enable quicker, more accurate patient diagnosis as well as to aid in the development of treatments for diseases like cancer and diabetes.

The computing and storage capacities of HPC have not yet been explored to their fullest extent. The design of high-performance computing provides maximum scalability and performance which can be applied to problems that imply complex and large volumes of data (Tulasi et al, 2015). Every scientific discovery and innovation that improves daily life is based on data, a reality that makes possible the affirmation that HPC underpins groundbreaking advancements in different sectors: industrial, scientific, societal etc. The volume of data at business level is growing at a fast pace, as technologies such the Internet of Things (IoT) and Artificial Intelligence (AI) are evolving rapidly. To stay ahead of the competition, businesses need lightning-fast, reliable IT infrastructure to process, store, and analyze vast amounts of data.

At the EU level, the European Commission recognizes the need to improve the HPC infrastructure and considers the benefits this technology offers. The EuroHPC JU program that will also be explored as part of this article, started in 2018 and its main objective is the development of infrastructure and skills in Europe (Rotună et al, 2021). In the following sections, we will look at the most important European initiatives in the field of HPC (section 2) and get into more detailed information about EuroCC project which represents the core of EuroHPC JU program (section 3). First, let us explore the PRACE partnership, an important dimension of HPC-related European initiatives.

EUROPEAN HPC INITIATIVES

PRACE

PRACE (Partnership for Advanced Computing in Europe) is a European initiative that seeks to promote impactful scientific discoveries and technological research & development in all fields to improve Europe's competitiveness for the benefit of society. It works to provide world-class computing and data management resources and services through a peer-reviewed process. PRACE also aims to empower industrial European users of HPC through various projects.

This partnership has 25-member states with their representative organizations, joining efforts to create a pan-European supercomputing infrastructure able to provide access to computing and data management resources and services at the high levels of performance for large-scale scientific and engineering applications. Its systems are available to worldwide scientists and researchers in academia and industry through specific forms of access presented on their official website.

More concretely, PRACE offers software and hardware technology initiatives with the aim of preparing for changes in technology used in research infrastructure and providing the appropriate tools, training and education to help the user community to adapt to these changes. The goal of these initiatives is to reduce the global cost of the system and its operation as well as its environmental impact.

Thus, PRACE aims to enable high-impact scientific discovery and engineering research and development across disciplines and sectors, and offer support to businesses and researchers in the field. Moreover, initiatives and projects launched by this organization also aim to improve energy efficiency when it comes to computing systems.

Among its success stories from clients, PRACE resources have been essential for a research group from the University of Helsinki in the space simulation with the Vlasiator space weather code. Vlasiator is a 6-dimensional simulation based on the Vlasov theory that has been created by the University of Helsinki. The goal is to use the kinetic hybrid-Vlasov approach to mimic the entire near-Earth space on a global scale, research fundamental plasma processes (reconnection, particle acceleration, shocks), and thus better understand space weather. Via PRACE, the study group has been granted access to the so-called Tier-0 (see Figure 1) supercomputers.

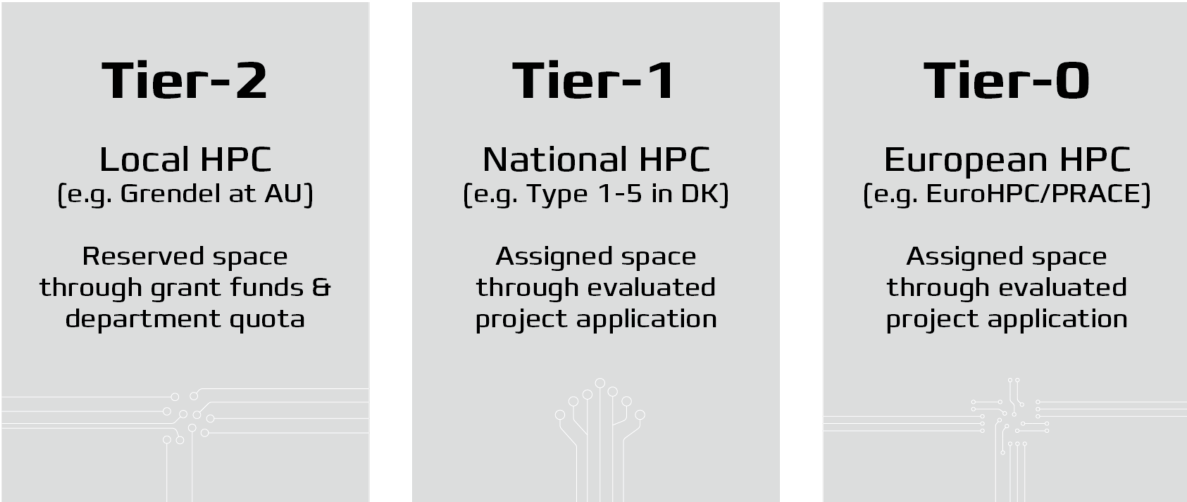

***Fig. 2:** Supercomputers Tier List (image source: www.deic.dk)*

Another research group from the University of Jyväskylä, Finland has been studying the structure and characteristics of gold and silver nanoparticles and their applications in chemistry. Their research assists scientists in developing vaccines against the viruses. The group has used the computing resources provided by PRACE network.

PRACE has developed a cutting-edge curriculum for HPC and scientific computing training, and it currently runs 14 PRACE Training Centers (PTCs).

Participants from the Member States (MS) of the European Union (EU) and Associated Countries to the Horizon 2020 program are welcome to enroll in PRACE training courses. PTCs conduct and oversee education and training initiatives that let European academic and business professionals use the PRACE-available computing infrastructure and offer training opportunities for computational scientists in Europe.

Focus COE

Another important HPC-related European initiative is FocusCoE (Centers of Excellence in HPC) that has run from December 2018 until March 2022 and has contributed to the success of the European High-Performance Computing ecosystem. The project supported the Centers of Excellence in HPC to more effectively fulfil their role, which is to ensure that extreme scale applications result in tangible benefits for addressing scientific, industrial or societal challenges.

There are twelve such centers of excellence: BioExcel, ChEESE, CoEC, CompBioMed, E-CAM, EoCoE, ESiWACE, EXCELLERAT, HiDALGO, MaX, NOMAD, PerMedCoE, POP, RAISE and TREX. From computing noise and fuel economies on aircrafts to evaluating the effects of climate change, HPC apps are making a difference to address a few of the world's most prominent social financial and scientific dares. The Centers of Competence (CoEs) in HPC recorded work to create such applications to assist society address current and advancing problems. As an example, certain COEs were effectively assisting in the battle against COVID-19 and HIDALGO created an application for modeling regarding human relocation and migration that made a difference in child saving associations to better react to the constrained migration phenomenon. Other centers proved to be exceptionally valuable within the execution and development of sustainable energy-related solutions.

FocusCoE has established the HPC CoE Council (HPC3), a framework including all active HPC CoEs and seeking to empower the role of applications in the European HPC ecosystem, and has supported its operations. This includes establishing contacts with a number of stakeholders associated with the European HPC environment.

Beyond HPC3, Focus COE facilitated industry outreach, organized training, analysis, and guidance across the CoE, collated the CoE's individual offerings, and presented them in a useful manner to external users. A comprehensive "CoE Brand" is created and promoted to widely disseminate the attractive HPC-related achievements and its contributions to society, economy, academia and industry. While FocusCoE ended, the centers of excellence (CoEs) continue their work, constantly benefiting from the assets that FocusCoE has created.

EuroHPC JU

The European High Performance Computing Joint Undertaking (EuroHPC JU), founded in 2018, is a Luxembourg-based legal and funding body that leads European supercomputing.

Its members are coming from both private and public sectors. From the public sector, its members include the following member states: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden and Turkey. From the private sector the following entities are a part of EuroHPC JU: the European Technology Platform for High Performance Computing (ETP4HPC), the Big Data Value Association (BDVA) and the European Quantum Industry Consortium (QuIC).

EuroHPC JU allows the European Union and EuroHPC JU member countries to coordinate their efforts and pool their resources to make Europe a world leader in supercomputing.

This strengthens Europe's scientific excellence and industrial strength and provides support for the digital transformation of the economy (industry 4.0), while ensuring technological sovereignty.

The promotion of digitalization throughout all of Europe is largely dependent on EuroHPC.

An essential component of the ecosystem is bridging the HPC and digital skills gap. Another crucial component of the European digital agenda is the integration of HPC with additional technologies like big data, cloud services, and artificial intelligence. Without high-performance computing, recent developments in artificial intelligence, like deep learning, which are already influencing society now and will do so significantly more in the future, would not be conceivable.

The EuroHPC Declaration (European Commission, 2018) has been endorsed by 32 nations. The signatory nations to the EuroHPC Declaration undertake to cooperate with one another and the European Commission to purchase, develop, and deploy a top-tier High Performance Computing infrastructure. No matter where supercomputers are located, the declaration calls for making such equipment accessible to scientific communities, public partners, and commercial investors throughout Europe. The joint procurement and deployment of exascale supercomputers that are accessible from anywhere in Europe and built on competitive European technologies is made possible by this integrated EuroHPC infrastructure, which will increase Europe's scientific capabilities and industrial competitiveness.

One of the central goals of EuroHPC JU is to create, deploy, scale up and keep up the world's driving common and secure ultra-connected environment for super and quantum computing-related information and services infrastructure within the EU. A main aim is to create and convey user-centered supercomputing frameworks based on a supply chain that ensures innovation and information that mitigate the hazard of disturbance, supporting the progress of a wide extend of dedicated applications.

Another objective of EuroHPC JU is to extend the use of this supercomputing infrastructure to a large number of public and private users and to support the development of essential HPC capabilities to European science and industry.

Considering the above, we can say that EuroHPC JU is the backbone of HPC European initiatives landscapes. A few considerations regarding the modality to access to EuroHPC JU will follow.

Access to EuroHPC JU resources

EuroHPC JU allows research institutes, public authorities, academia and industrial actors based in EU or in a state associated with Horizon 2020 to apply for accessing the supercomputer Euro-infrastructure (europa.eu, 2018). Access is granted after a successful application through one of the open calls provided by EuroHPC JU.

European organizations are eligible for access to conduct Open Science research (results of research will be made available in open access). This encompass public and private higher education and research institutions, public sector organizations, industrial companies and small and medium enterprises.

Interested companies are to apply for access via one of the EuroHPC calls for system access. Applications are reviewed based on specific criteria set forth in each call. The type of documentation and required information for each access type can be found here. Access to supercomputers is currently granted free of charge.

EuroCC PROJECT

Within the EuroHPC JU framework and as part of the European Union's Horizon 2020 (H2020), the EuroCC project which is currently still in progress, envisions the creation of National Competence Centers (NCC) in the field of HPC in each member state. These centers coordinate activities in all HPC-related fields at the national level and act as contact points for industry, academia, HPC professionals, and the general audience. EuroCC projects are 50% funded by Horizon 2020 – EuroHPC JU joint venture and 50% by partner national funding programs.

With the participation of 33 Member States and affiliated states, EuroCC's activities are under the coordination of the High Performance Computing Center Stuttgart (HLRS). HLRS provides crucial tools and solutions for academic and corporate research, particularly in the sciences and computational engineering, as it is home to one of Europe's most advanced supercomputers and having a substantial team of HPC specialists. Additionally, HLRS is continually looking for ways to use data analytics, high-performance computing, and similar technologies in other fields where they might have an impact (HLRS Annual Report, 2021).

The EuroCC project seeks to bring its members to a uniform elevated level in the domains of HPC, HPDA and artificial intelligence (AI). In this sense, the EuroCC project has founded National Competence Centers (NCCs) in participating nations. The NCCs are responsible for collecting and documenting HPC, HPDA and AI core activities and competencies in each country. The ultimate goal is to bring HPC-resources to different users in science, industry, government and society.

EuroCC seeks to address the need of European countries to increase their HPC competencies. The project mobilizes the necessary expertise to create a network of National Competence Centers in HPC across the 33 EU and associated states. The project offers an overview of the vast service portfolio customizes to the particular national needs of public administrations, academia and industry. EUROCC aims to consolidate the national competencies of HPC as well as high-performance data analytics and national artificial Intelligence (AI) capacities to diminish existing gaps in the usage of these technologies.

In connection to EuroCC, the Coordination and Support Action (CSA) CASTIEL encourages interaction and expertise-sharing over the whole EuroCC system. As the project works to create a Europe-wide competency outline showing accessible assets and information gaps over all the national competence centers. This empowers potential collaborations, sharing of information and skills between diverse countries to proficiently address gaps. CASTIEL organizes exercises like global workshops, mentoring and twinning collaborations, in order to respond to matters of common interest. In this way, CASTIEL interfaces the National Competence Centers (NCCs) within EuroCC to a European network.

Competency working groups in HPC, HPDA and AI illustrate the worldwide competitiveness of the European partners. These two exercises represent the start of the vital situating of HPC capabilities in Europe and a contribution to the comprehensive independence of related technologies in the European space.

RoNCC

Within the EuroCC project and in the framework of EuroHPC JU, the National Institute for Research-Development in Informatics - ICI Bucharest, Romania founded the Romanian National Competence Center (RoNCC). A single National Competence Center (NCC) in the field of high-performance computing (HPC) must be established in each participating nation as part of the EuroCC project under the European Union's Horizon 2020 (H2020) initiative. These NCCs serve as a focal point for clients from business, science, HPC professionals, and the general public while coordinating activities in all HPC-related sectors on a national scale. The High-Performance Computing Center Stuttgart oversees the EuroCC activities.

The National Competence Centers (NCC) established under EuroCC are combined into a pan-European network by CASTIEL, the Coordination and Support Action (CSA) directly related to EuroCC. The combination of HPC, High Performance Data Analytics (HPDA), and AI skills underlines the EU partners' ability to compete internationally. The two initiatives mark the start of a strategic positioning of European HPC expertise and will support the full independence of the aforementioned technologies in Europe.

The Romanian HPC Center works to create a network of competencies in HPC – High Performance Computing, operating as an interface and contact point to facilitate access to resources and capabilities in HPC, both in Romania and in Europe, through the EuroCC network. Therefore, RoNCC will offer relevant resources for public institutions in Romania, educational and academic institutions, users and providers of IT services and to other interested parties.

Particularly, one of the objectives of the competence center is to create and constantly develop a comprehensive map of the national existent HPC competences and related institutions. Another mission is to act as a contact point for academia and industry, matching these actors with providers that suit their needs and offering relevant expertise, at national or international level. Besides these two objectives, the center also collects training offers in the field of HPC, displaying them in a common space with the other competence centers.

RoNCC as well as the other national competence centers offer support in regard to different HPC competencies such as events that explain what High Performance Computing, High Performance Data Analysis and Artificial Intelligence are and why they are important to organizations. The objective of the project is to get all of the participating nations up to a high level in the disciplines of HPC, HPDA, and AI (AI).

In order to accomplish this, the EuroCC project has set up National Competence Centers (NCCs) in each of the participating nations. The NCCs are also in charge of assessing and cataloging the primary HPC, HPDA, and AI activities and competencies in each nation as part of the task of competence mapping mentioned before. The ultimate objective is to make HPC accessible to various users from research, business, government, and society.

CONCLUSIONS

The main intention of this article was to highlight the relevance of the rapidly evolving use of HPC-related technologies within the European space, as part of a global trend.

Firstly, a broad definition of this concept and of related notions were given and some of the main benefits of HPC for citizens, science and industry were presented. In section 2, a selection of HPC use cases was proposed that sought to make clear the numerous applications of HPC in various spheres After this overview, the article moved to looking at some of the core European HPC-related initiatives: PRACE and Focus COE, and moving to the EuroHPC JU program and the modality to access its resources. Within the framework of the afore-mentioned program, the EuroCC project is one of its main tools, as seen in section 4. Finally, in section 5, the Romanian Competence Center in

HPC within the EuroCC project was also presented, thus zooming into the national level from the perspective of HPC services and initiatives.

With regard to the future of European HPC, the European Commission intends to build up supercomputing and data processing capacities by buying world-class exascale supercomputers, post-exascale facilities, and supporting an ambitious High Performance Computing research and innovation agenda. Considering all of the above, it is safe to conclude that, as part of the digital decade, HPC is key to Europe's future prosperity, digital transformation and resilience.

ACKNOWLEDGMENT
This work has been carried out as part of the EuroCC project.

REFERENCE LIST

COMMISSION STAFF WORKING DOCUMENT. (2020). *Equipping Europe for world-class High Performance Computing in the next decade*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020SC0179&from=EN

EuroHPC JOINT UNDERTAKING. (2022). *DECISION OF THE GOVERNING BOARD OF THE EuroHPC JOINT UNDERTAKING No 16/2022. Adopting rules on the prevention and management of conflicts of interest of the staff members of the EuroHPC Joint Undertaking*. Retrieved from https://eurohpc-ju.europa.eu

European Commission. (2018). *The European declaration on High-Performance Computing*. Retrieved from https://digital-strategy.ec.europa.eu/en/news/european-declaration-high-performance-computing

European Commission. (2021). *The European High-Performance Computing Joint Undertaking* - EuroHPC JU. Retrieved from https://digital-strategy.ec.europa.eu/en/policies/eurohpc-ju

FocusCoE. (2020). *D2.3-First Summary of Consolidated CoE Input document* (Project Number: 823964). Retrieved from https://www.hpccoe.eu/wp-content/uploads/2022/07/D2.3-First-summary-of-consolidated-CoE-input-provided-to-the-EU-HPC-ecosystem.pdf

Focus CoE. (2021). *BEST PRACTICES BOOKLET FOR SECTORIAL EVENTS*. Retrieved from https://www.hpccoe.eu/wp-content/plugins/pdf-viewer-for-elementor/assets/pdfjs/web/viewer.html?file=https://www.hpccoe.eu/wp-content/uploads/2022/01/FOCUS-COE-BOOKLET-SECTORIAL-EVENTS-PHYSICAL-EVENTS_SW-AUGUST-2021.pdf&embedded=true

Fuller, A., Fan, Z. & Day, C. (2020) Digital Twin: Enabling Technologies, Challenges and Open Research. *IEEE Access*, *8*, 108952-108971. DOI: 10.1109/ACCESS.2020.2998358

High Performance Computing Center Stuttgart. (2021). *2021 Annual Report*. Retrieved from https://www.hlrs.de/about/profile/annual-report

Interreg Danube Transnational Programme. (2019). *InnoHPC High Performance Computing and innovations in the Danube Region*. Retrieved from https://www.interreg-danube.eu/approved-projects/innohpc

Rotună, C., Cîrnu, C. E., & Dinu, A. (2021). Smart cities powered by HPC. R*omanian Journal of Information Technology and Automatic Control*, *31*(2), 35-44.

Saurabh, V., Prashant, A., & Santosh, B. (2018). Industry 4.0 – A Glimpse. *Procedia Manufacturing*, *20*, 233-238.

Tulasi B., Rupali, S. V., & Balaji, S. (2015). High Performance Computing and Big Data Analytics – Paradigms and Challenges. *Journal of Urban Technology*, *116*(2), 28-33.