5 Investing in digital infrastructure

This chapter discusses the policy context and policy directions related to investment in digital infrastructure in higher education systems across the OECD and EU Member countries. It proposes general principles for maximising the benefits of investments in digital infrastructure within the Croatian higher education system. It also categorises digital infrastructure into different types and analyses each in turn, providing specific advice to be considered for each type of infrastructure.

Policy context: Modernisation and digitalisation of higher education in Croatia

In the past decade, global investment in educational technology is estimated to have increased more than 20-fold, from USD 0.7 billion in 2011 to USD 20.8 billion in 2022 (IDB and HolonIQ, 2021[1]). Digital technologies are an increasingly important part of education and training systems worldwide, supporting institutional planning, administrative and operational processes, the management of physical and human resources, and research activities[1]. Through digitalisation, it is possible to increase access to learning resources, transform teaching and learning practices, streamline business processes and improve decision-making.

Digital infrastructure in higher education is part of the overall digital landscape of a country, and a crucial pillar of the wider digital economy, defined by the OECD as follows (OECD, 2020[2]),

> *The Digital Economy incorporates all economic activity reliant on, or significantly enhanced by the use of digital inputs, including digital technologies, digital infrastructure, digital services and data. It refers to all producers and consumers, including government, that are utilising these digital inputs in their economic activities.*

The success of a digitalisation strategy depends on a robust foundation of connectivity and equipment, and the tools and capacities needed to use it. Tackling connectivity and equipment gaps is one of the fundamental factors for the success of digital transformation agendas in education systems (European Commission, 2022[3]).[2] This means the wider state of digital infrastructure partially determines the digital readiness of higher education systems, and is a key factor in the digital maturity of individual higher education institutions, along with digital leadership, digital competence and digital culture (see Chapter 3).

Croatia's higher education system has been undergoing a series of reforms, as part of a comprehensive modernisation programme. One of the aims of this programme is to improve the digital infrastructure in Croatia's higher education system, with major investments currently underway (Box 5.1).

Box 5.1. Croatia's e-Universities project

Croatia has implemented a programme to comprehensively reform its higher education sector. This is part of the country's National Plan for Recovery and Resilience 2021-2026, a suite of reforms to modernise higher education, and improve its relevance, quality and availability to the population.

The reforms include "e-Universities", an ambitious digital transformation programme for the higher education sector. Launched in 2022, the programme aims to strengthen investment in the digital infrastructure of higher education institutions. Objectives of the programme include upgrading on-campus networks, improving Internet backbone connectivity, and investments in equipment, central provision of educational applications and resources, training and capacity-building services. A key target is for at least 90% of public higher education institutions in Croatia (comprising public universities, polytechnics, and colleges) to benefit from improvements in their infrastructure.

e-Universities also seeks to develop the digital competence of users in higher education. For this part of the project, the Croatian Academic and Research Network (CARNET) will partner with the National University Computing Centre (SRCE), the Agency for Science and Higher Education (ASHE) and the National and University Library in Zagreb (NSK).

Source : CARNET (2022[4]) e-Universities, https://www.carnet.hr/en/projekt/e-universities/.

During the crises prompted by the COVID-19 pandemic and the 2020 earthquakes in the Zagreb area, decisions about digitalisation needed to be made quickly and in challenging circumstances. While on-campus provision has made a welcome return, Croatia's higher education institutions are still in need of more robust Internet connectivity, computing equipment and many other digital tools. Much remains unknown about the impact of digitalisation for teaching and learning, and, unlike investments in buildings and other physical infrastructure, the development of widely recognised standards and criteria for evaluating digital investments remains nascent. Nonetheless, in Croatia as in other countries, there is an imperative to move forward with investments, particularly in areas where the pandemic highlighted deficiencies in existing infrastructure.

This chapter brings together evidence and expert advice on the current state of digital infrastructure in higher education systems. It defines and categorises digital infrastructure, reviews recent trends in practice for each defined category, and presents important considerations for designing, scoping and implementing public infrastructure investments. The information in the report can support Croatia to make national decisions about public investments in digital infrastructure. Annex B presents a set of guidelines, based on the analysis in this chapter, to inform the development of investment strategies for digital infrastructure within individual higher education institutions.

Definition and categorisation of digital infrastructure in this project

Definition

Digital infrastructure is often referenced in commercial reports and public policy documents, but rarely precisely defined. Many definitions focus only on connectivity and equipment. Taking such a narrow view risks overemphasising the technology itself rather than its use, and may result in investment that does not necessarily advance improvements in higher education provision. As a result, there is an increasing tendency towards a more holistic view of digital infrastructure, encompassing both “hard” (physical) and “soft” (non-physical) elements. The physical category includes networking, processing, and storage, while the non-physical soft category includes end-user hardware such as computers and smart devices, central applications and software services (AIIB, n.d.[5]).

To truly achieve digital transformation, building digital infrastructure must go hand-in-hand with building digital competence. User capability is also part of digital infrastructure: staff and students must be proficient in operating and benefiting from the provided equipment and software. Digital infrastructure is generally not defined to encompass pedagogy. It is often considered to be pedagogically neutral, serving only as the backbone for pedagogical development and innovation, although this is a somewhat contested view (Facer and Selwyn, 2021[6]).

A fit-for-purpose digital infrastructure in higher education systems is a constantly moving target. Objectives and standards for digital infrastructure will be adapted as higher education systems themselves evolve their technologies and pedagogies, and new skills requirements, programme designs, and delivery modes emerge.

Thus, digital infrastructure in higher education comprises the basic systems, services, and competence required for institutions to work effectively to meet their objectives for digital transformation. Bringing these considerations together, the definition used for the purposes of this report is as follows:

> *Digital infrastructure brings together and interconnects physical and virtual technologies and associated supports, enabling higher education institutions to facilitate high quality education and research in an evolving digital landscape.*

Categorisation

The categorisation of digital infrastructure can help to provide structure and clarity to investment strategies, by enabling the development of procurement policies and frameworks for specific classes of infrastructure. Categorisation can also help to identify where responsibility for provision sits, for example at a national level, at institutional level, or at individual level. With this in mind, and drawing on a range of other classifications (for example (NIFO, 2022[7]; NFTLHE, 2017[8])) for the purposes of this project, digital infrastructure is classified into five main analytical categories:

1. Networking (including long-haul, on-campus and off-campus networking)
2. On-campus technical equipment (including servers and audio-visual equipment)
3. End-user hardware (devices for students and staff)
4. Software (including end-user software and central software applications)
5. Competence and capability services for staff and students to use digital technologies.

The following sections provide more granular analysis of the infrastructure categories defined above and propose specific principles to shape investment decisions from public funds for each of these infrastructural elements. The analysis of digital competence and digital capability is generally outside the scope of this chapter but is covered in more detail in Chapters 2, 3 and 4. Nevertheless, this chapter concludes with a short reflection on the topic, underlining the importance that investment in digital infrastructure can only be fully effective when people have the capabilities to effectively engage with the available technologies.

Effective investment in higher education digital infrastructure

This section investigates recent trends in public authorities' approaches to supporting investment and innovation in the digital infrastructure of higher education institutions. It analyses the sources of financing and provision of infrastructure from the perspective of higher education institutions. It also provides a set of general recommendations for public authorities to consider when supporting the development of digital infrastructure within higher education systems. Key reflections can be summarised as follows:

- Public authorities and institutions need to find a balance between ensuring there is adequate public investment in institutions' digital infrastructure (directly or through intermediaries such as NRENs) and avoiding the risks of overdependence on any one source of funding.
- Capital and project-based funding is the most prominent means of public investment in digital infrastructure. While capital investment enables large infrastructure projects, attention must be paid to the need for continuing recurrent funding for infrastructure support and maintenance. In some circumstances, digital equipment leasing, virtualisation and cloud-based applications are converting traditional capital investment to current expenditure, with possible implications for future funding models.
- Governments can support institutions with digital infrastructure development and procurement processes through direct provision of infrastructure, by supporting collective procurement processes, and by multiplying opportunities for knowledge sharing of procurement practices and efficacy of educational technologies.
- Public authorities need to find a balance between offering more support to institutions with less capacity for developing digital infrastructure and ensuring that more empowered institutions have the freedom to make use of public investment to serve their digital priorities.
- Governments should reserve a share of public funding to promote an entrepreneurial approach to infrastructure development, and encourage collaboration between higher education institutions, organisations in the private sector and other stakeholders.

Resourcing the provision of higher education digital infrastructure

Despite the success of the Bologna process, there remain big differences across Europe in the ways that higher education institutions are created, regulated, and funded. These differences affect the institutions' ability to raise financing from different sources (EHEA, 2022[9]). Nevertheless, most higher education institutions have several potential public and private funding streams to resource investments in digital infrastructure. Overdependence on public funds, or indeed any one source of financing within higher education systems, creates risks. For example, many higher education institutions in Europe experienced severe difficulties following the onset of the late-2000s global financial crisis as governments in certain countries had to rapidly cut public expenditure (Ritzen, 2015[10]).

In Croatia, public funding is the largest source of income for public institutions, as for the majority of EU and OECD countries (European University Association, 2021[11]). Other vehicles available to Croatian higher education institutions for funding digital infrastructure include local budgets, tuition fees, revenue generated from research and scientific projects, as well as donations and commercial activities. All such forms of revenue are permitted by public authorities, as long as the activity remains within the boundaries of the mission and goals of the institution and does not affect the institution's credibility and independence (Eurydice, 2021[12]).

Responses to the 2022 OECD-CARNET digital maturity survey of higher education institutions indicate that the central government is not the most common source of funding for digital infrastructure in Croatian public higher education institutions (see Chapter 3). More than 80% of public institutions use their own budget as a source of funding for digital infrastructure, while about 60% of institutions use funds allocated by the central government. European Union funding is an increasingly important source of funds for digitalisation in Croatian higher education institutions, particularly for funding digital tools and technologies in research projects. The survey was not able to collect more detailed information on the respective shares of funding for digital infrastructure from each source, but still provides a basic insight into access to funding streams.

The expansion and diversification of the funding mix for digital infrastructure encourages Croatia's institutions to take a more entrepreneurial approach to their activities, to become less dependent on government funding and to potentially accumulate surpluses of revenue that could be invested in their goals for digitalisation (OECD/EC, 2019[13]).

The special role of National Research and Education Networks

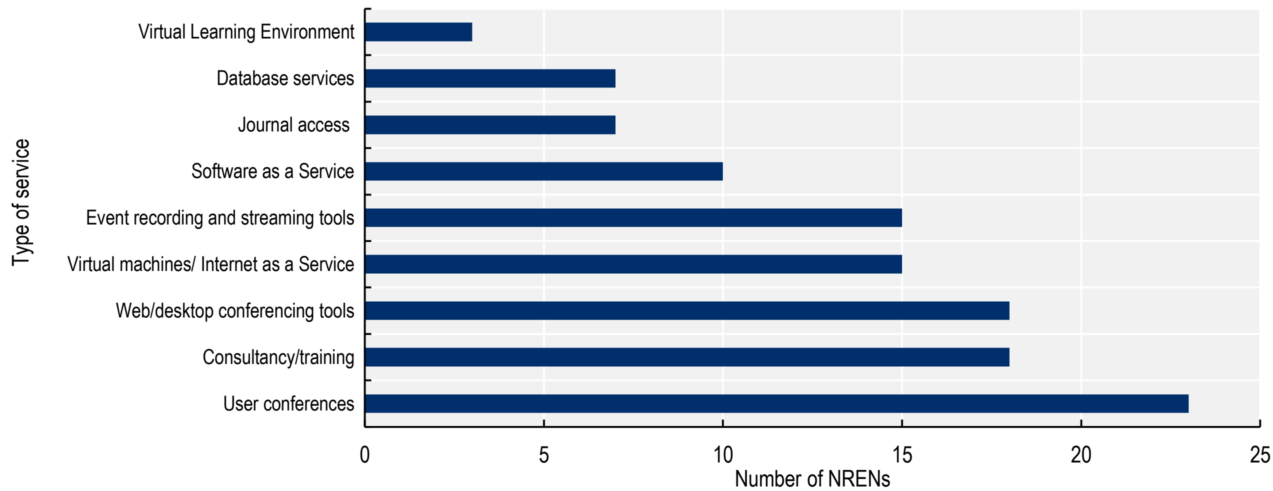
National Research and Education Networks (NRENs) – specialist national Internet service providers whose main client group is education and research institutions – play a prominent role in the development and maintenance of digital education infrastructure across OECD countries. NREN operations may be funded in several ways, including through grants from public bodies, and financial contributions from client organisations (GÉANT, 2022[14]).

In European countries, NRENs are usually the sole providers of fixed and wireless high-capacity Internet connectivity for higher education and research institutions (GÉANT, 2020[15]). However, as Figure 5.1 shows, NRENs have come to play an important role in providing higher education institutions with services that are complementary to Internet connectivity. They also frequently provide higher education systems with opportunities for improved efficiency, interoperability and economies of scale. Many NRENs in Europe now offer cloud storage, web/desktop conference tools, and other services. Finally, NRENs are increasingly collaborating with each other and sharing information educational technologies, supported by platforms such as the GÉANT Task Force on Educational Technologies (GÉANT, 2022[14]). The collective services developed and delivered by NRENs are especially beneficial to small institutions that may lack the resources and capacity to create bespoke local solutions.

CARNET is an example of an NREN providing a much wider range of services to client organisations than Internet connectivity alone. In total, CARNET provides approximately 40 distinct services to more than 200 000 users in higher education and research organisations (GÉANT, 2022[14]). CARNET played a leading role in the deployment and upgrade of digital infrastructure in Croatia's e-Schools project and plays a similarly important role in the development of the e-Universities project (Box 5.1).

Figure 5.1. Selected services provided by NRENs in Europe

Number providing each service, out of 26 European NRENs



Source: OECD analysis of the online GÉANT Compendium, https://compendium.geant.org/#!/.

StatLink https://stat.link/tu23ln

Policy directions for public investment in higher education digital infrastructure

Enhancing the availability of digital equipment and Internet connectivity has been central to almost all digital strategies in education in OECD countries (OECD, 2020[16]). Public authorities may draw on several financial, operational, and organisational policy levers to support investments in digital infrastructure. This section analyses potential policy directions that public authorities may choose when supporting and prioritising investments in digital infrastructure.

Rethinking public funding models to meet digital infrastructure needs

Within higher education systems, public funding for purchasing physical infrastructure has traditionally been carried out through capital funding allocations. Public capital expenditure tends to be linked to overall government financial conditions rather than conditions within education systems. As a result, the amount available for capital expenditure in higher education can vary significantly from year to year (OECD, 2019[17]). Major infrastructural projects or showcase investment tend to be triggered by application/competition among potential beneficiaries, with applications reviewed and categorised according to a set of agreed ranking criteria. Minor projects are often enabled by devolving funding so that individual institutions can carry out the work, sometimes with central guidance. Capital investments in fixed physical infrastructure have implications for current expenditure commitments. Recurrent funding needs to be anticipated and committed for maintenance contracts (though supplier maintenance and support is sometimes included in the capital cost), and local staff costs.

As with physical capital infrastructure projects, digitalisation projects tend to be funded by public authorities using one-off targeted or project-based allocations (OECD, n.d.[18]). However, digital equipment leasing, virtualisation and cloud-based applications are increasingly commonplace in higher education systems, replacing previously one-off costs for the purchase of tangible items (e.g. physical servers) with recurrent costs. Furthermore, cloud service costs can vary according to how much of the resource (e.g. processor time) is consumed, unlike the fixed costs associated with the purchase of physical on-site equipment.

Thus, planning and resource mobilisation for digital infrastructure increasingly needs to be considered as a multi-year process. This has implications for current institutional funding models operated by many public authorities, which largely provide core public funding on an annual basis based on a formula-funding methodology that does not consider the extent of digital activities or needs.

In some jurisdictions, public authorities have adopted a specific strategic position for funding digital infrastructure. In Norway, for example, the 2017-21 digitalisation strategy for the higher education sector stipulates that digitalisation should generally be integrated into the operational activities of higher education institutions, and that users of digital tools and technologies should be primarily responsible for financing digital innovations, with central funding provided for specific stimulus measures only (Box 5.2). Negotiating agreements on the locus of responsibility for different costs at the planning stages of digital infrastructure investments can support realistic forecasting of financial needs across the system.

Box 5.2. Norway's approach to public investment in digital infrastructure

Norway's digitalisation strategy for the higher education sector (2017-2021) recognises the collective need for digitalisation strategies to be in place at both the institutional and national levels. Its sub-strategies focus on research, education, infrastructure, administrative solutions and data security (OECD, 2021[19]) .The government adopts the following position with regard to financing infrastructure:

> *The Norwegian Ministry of Education and Research will continue to contribute to the further improvement and expansion of state instruments for quality development and national infrastructure under the auspices of UNINETT…. The INFRASTRUCTURE scheme of the Research Council of Norway (RCN) could be a relevant source of funding for investments in and upgrades of nationally important ICT research infrastructure.*
>
> *However, the primary principle for financing ICT infrastructure and services in the higher education sector must be that the institutions (users of the services) pay the cost of performing the tasks.*
>
> *Digitalisation is not something that comes in addition to normal activities but must be integrated into them. The government has clear expectations that digitalisation will lead to solutions that are more efficient and better meet the needs of users, that realise benefits, and that free up resources that can further support digitalisation to improve quality. Consequently, central funding primarily caters for the financing of selected development projects and specific stimulation measures, while running costs for operation, maintenance, and innovation are financed by way of prioritisation within the usual budget frameworks. The government has established a co-financing scheme managed by Agency for Public Management and eGovernment (Difi) for small and medium-sized businesses. State enterprises, including state-owned HEIs, can apply for funding for up to 50% of the project costs. The projects must be socio-economically profitable and provide a solid realisation of benefits.*

Source: Government of Norway (2017[20]), Digitalisation strategy for the higher education sector 2017-2021, https://www.regjeringen.no/en/dokumenter/digitalisation-strategy-for-the-higher-education-sector-2017-2021/id2571085/?ch=5

Developing acquisition strategies to enable economies of scale and empower efficient and effective investment

For education institutions to take responsibility for the acquisition of digital education infrastructure, they need sufficient information, capacity, and skills to navigate the wealth of options for digital products, services, and tools. To make decisions about infrastructure purchasing, they also require a comprehensive understanding of student and staff needs to ensure that digital tools are fit for purpose.

Procurement is a commercially confidential process between higher education institutions and suppliers. Even in the case of collective purchasing, pricing details are often withheld, and commercial confidentiality clauses prevent the release of cost information. As a result, institutions may purchase technology that is ineffective, difficult to support locally, or incompatible with existing infrastructure. In countries with reducing populations (and therefore reducing market size), commercial technology providers may need to charge higher sales costs and experience fragmented demand for their products, potentially discouraging them from entering or remaining in the market. Developing procurement strategies at the collective or system level is essential for addressing these information asymmetries and potentially negative market forces. Furthermore, a collective approach can ensure that suppliers do not exploit the lack of information available to individual institutions about the market.

One way in which governments can bridge information gaps and support choices about available technologies and providers is through knowledge dissemination platforms that help to guide procurement decisions. In the United Kingdom, for instance, there is an education procurement guidance service that explains the benefits of using existing frameworks, proposes cost-efficient alternatives and supports compliance with the relevant procurement regulations (Gov UK, 2022[21]). In the Netherlands, SURF (the Dutch NREN) relies on a combination of peer learning and expert advice to guide digital infrastructure choices for over 100 member institutions (SURF, 2022[22]).

NRENs are important actors in procurement processes in many countries, providing purchasing frameworks tailored to higher education in areas such as dark fibre access and software purchasing. In Lithuania, for example, NRENs provide centralised hosting services such as Zoom and Moodle as well as network connectivity (LieDM, 2022[23]). Ireland's NREN HEAnet brokers hardware, software, support, and professional services on behalf of institutions, effectively streamlining procurement processes and negotiating aggregate deals from which all members can benefit (NFTLHE, 2017[8]). Several NRENs in Europe support the purchasing of cloud services, while GÉANT offers framework contracts for institutions to buy cloud services without running their own tendering process (GÉANT, 2022[14]).

Collective procurement processes for digital infrastructure can also be designed to benefit individuals. For instance, many governments have made agreements for staff and students to access preferential pricing for end-user devices and software. Such agreements also indirectly benefit higher education institutions, alleviating the pressure to provide students and staff with hardware and applications.

Direct provision of common-good elements of digital infrastructure by public authorities

An alternative model for delivering investment in digital infrastructure is through direct tendering and public authorities providing resources to higher education institutions. Such direct provision can be beneficial especially for smaller institutions with less access to financial resources from private sources, or with fewer staff with strong digital capabilities. The most common form of direct provision is provision of centralised software and applications, such as virtual learning environments or student information systems. Examples of such common-good provision can be found in the Croatian higher education system: the Computing Centre of the University of Zagreb (SRCE) supports a version of the Moodle learning management system tailored to the Croatian higher education system, which is widely used across the system. In addition, the Ministry of Science and Education provides funding for a central licence for the Microsoft 365 productivity suite, also used widely throughout the system.

Some jurisdictions offer direct provision and support of local area networks as well as backbone Internet access. Managed network services provide a viable alternative to institutions struggling to attract and maintain network engineering and maintenance staff on-site, or institutions over dependent on the presence of specific employees to ensure reliable network services (GÉANT, 2022[24]). In the United Kingdom, for example, small faculties and institutions may access a managed router service (Network Management as a Service) where the NREN takes over network management tasks (Jisc, 2022[25]). Some NRENs in Europe have also started to offer Campus Network as a Service (CNaaS), providing a fully managed local area network for higher education campuses.

Recommendations for effective public investment in digital higher education infrastructure in Croatia

Digital infrastructure investment strategies need to be tailored to the capacity, autonomy, and governance arrangements of diverse higher education institutions

Public investment schemes for digital infrastructure in higher education systems differ from investment schemes for schools in important ways. Higher education institutions operate at a much larger scale than schools, and they are more heterogeneous, encompassing education, research, and engagement activities. This means they have more extensive and diverse digital technology needs. The two sectors also differ in terms of their level of autonomy. In comparison to higher education institutions, schools typically have less independence in defining their educational offer and operations, and are subject to common learning achievement targets, often measured through standardised assessments. As a result, schools are more of a "captive audience" for public policy initiatives in digitalisation, having limited recourse to other options for financing the development of digital infrastructure.

The design and implementation of one-size-fits-all solutions for schools is much less likely to work for higher education institutions. The more empowered position of some higher education institutions has implications for planning public investments on their behalf. Many institutions have evolved a highly proficient approach to procurement, both individually and collectively, putting them in an advantageous position with commercial suppliers. Furthermore, as managerialism increases across higher education systems, more professionalism is being injected into the evaluation of investment decisions. This means many higher education institutions have investment capabilities similar to large commercial organisations (OECD, 2019[17]). Such institutions may not benefit from publicly provided infrastructure that is inadequately tailored to their bespoke needs and not aligned with their existing support processes.

Within the context of national and supranational regulations for procurement and governance, higher education institutions are afforded different degrees of freedom in choosing suppliers for their digital infrastructure needs. In the most centralised systems, public authorities play a leading role in the procurement of infrastructure, with a state actor purchasing ICT equipment on behalf of higher education institutions. For instance, in Hungary, the procurement requests of all public higher education institutions are considered, prioritised, and fulfilled by a national agency (OECD, 2021[26]). In exercising full control over procurement, governments aim to reduce the complexity and risks of procurement, improve efficiency by avoiding duplication and ensure infrastructure meets quality and interoperability standards. Conversely, centralised services can be perceived as inflexible, slow and with limited latitude for investment in innovations or specialised items that are not highly prioritised nationally (OECD, 2021[26]).

In the most autonomous systems, by contrast, education institutions have complete freedom to decide on their digital infrastructure investments. In the United Kingdom, public institutions have full autonomy to manage their digital infrastructure, although they may use multiple national and regional procurement frameworks for educational technology through the Crown Commercial Service (Crown Commercial Service, 2022[27]), or form purchasing consortia for collaborative procurement (UKUPC, 2022[28]). Similarly, the Flemish Community of Belgium established a framework agreement with the private telecom sector and software resellers to provide better procurement conditions for educational institutions (van der Vlies, 2020[29]).

Other countries have opted for a middle ground, centralising a limited range of digital services that are subject to less personalisation and have an overarching impact on the security of the system. In Norway for instance, the Norwegian Directorate for ICT and Joint Services in Higher Education & Research (now merged into Sikt, a new service provider for the knowledge sector) offers a common ICT architecture to centralise, harmonise and standardise services related to security and access (UNIT, 2021[30]). At the same time, it gives institutions the freedom to choose services that can be tailored to their needs, such as virtual learning environments (OECD, 2021[26]). Croatia would appear to fall into this middle ground, with a strong offer of centralised infrastructure and services provided by the Ministry of Science and Education, CARNET, SRCE and others, while institutions are free to procure additional solutions.

There is limited comparative evidence on the procurement strategies for different forms of educational technology and their impact. Decentralised procurement practices enable institutions to benefit from flexibility in choosing products and tools aligned with their specific needs. At the same time, not every higher education institution is in the favourable position described above. For example, smaller institutions or institutions with decreasing enrolments may have a reduced capacity to engage in the resourcing and procurement of digital technologies and may therefore benefit from more support from public authorities.

Future investment strategies for digital infrastructure in Croatia should reflect carefully on which elements of digital infrastructure are best provided centrally, and which are best left to individual institution decisions. Public investments stand the best chance of being effective when planned and delivered in consultation with higher education institutions, and in concert with their existing infrastructure.

Beyond providing for basic needs, a share of public investment should be allocated to promoting innovative and entrepreneurial approaches to digital infrastructure

Governments can rely on a mix of policy approaches to support digital innovation in educational technology. Previous OECD work has identified a number of important measures that can be taken to stimulate innovation, including: targeting regulatory burdens for start-ups, promoting diversified financing options for new entrants, mobilising the private and public sector to support digital innovation, incentivising innovation through tax credits, and policy experimentation (OECD, 2019[31]; OECD, 2020[32]).

When enrolments are falling, as has been the case in Croatia, commercial companies are less likely to invest in innovations that rely on maximising returns by scaling up rapidly to a large user base. In turn, this may lead investors to focus on existing or familiar technologies rather than on more innovative and potentially riskier alternatives (Reich, 2020[33]).

Croatian public authorities can help support the innovation ecosystem of digital education through existing and future policy instruments and public investments. Policies to boost digital innovation in education cannot be conducted in isolation. When it comes to digital infrastructure and innovation, a range of policy measures across various sectors help to shape the overall ecosystem. According to a recent evaluation, Croatia has relatively low levels of research and development activity in its enterprises, as well as resource constraints that may limit higher education institutions' capacity to innovate (OECD/EC, 2019[13]).

Regardless, even with resource constraints, public authorities can stimulate innovation by allocating a small share of public investment reserved for digital infrastructure to funding novel or experimental infrastructure arrangements. Funding programmes for experiments in digital education technology can be designed in various ways, including calls for individual institution applications, investing in innovation labs or even developing disruption vehicles for higher education digital infrastructure, similar to Denmark's Digital Disruption Task Force (OECD-OPSI, 2021[34]).

Co-ownership of investments with beneficiaries and partnerships can spread the risks of innovation and ensure digital infrastructure addresses need appropriately

Public financing models can and should focus on encouraging contribution and effort from both the private sector and beneficiary higher education institutions. Creating incentives for the private sector to invest in innovation for digital education requires expertise in and understanding of the educational technology market (World Bank, 2020[35]). Governments should have the means to monitor investment and developments in the educational technology industry, in order to gain an understanding of the dynamics of the market, including the presence of potential market failures (Vincent-Lancrin, Cobo Romaní and Reimers, 2022[36]).

Partnerships between diverse stakeholders can incentivise private investments, particularly for unproven technologies. For instance, partnerships between start-ups, universities, industry and government can facilitate innovation by providing start-ups with opportunities for funding as well as the chance to test tools, services, or products (OECD, 2019[31]). Governments can also encourage better collaboration between higher education institutions and developers of educational technology to ensure that new tools and equipment match the specific requirements of institutions, educators and learners. Students' and educators' involvement in the R&D/product development process is crucial to ensure digital technologies are designed with the needs of the learning ecosystem in mind.

Potential investment choices in digital infrastructure should be evaluated according to a robust set of centrally defined criteria

The definition and publication of criteria for evaluating and making decisions about public fund allocations should promote fair and transparent decision processes. As mentioned in the previous section, potential public capital investments in higher education are often evaluated according to a set of centrally defined criteria that consider system-level goals and objectives. Similarly, criteria for planning and prioritising investment digital infrastructure should also be defined. Many sets of criteria to evaluate public investments have been proposed by national and international bodies. Box 5.3 presents a list of potential criteria than can be used to evaluate and prioritise investments for digital higher education infrastructure, in contexts where systemic needs outweigh available budgetary resources.

Investment considerations and resulting criteria may differ according to the type of digital infrastructure investment. The following sections provide a more detailed analysis of network connectivity, on-campus technical equipment, end-user hardware, and software for higher education campuses respectively, detailing specific considerations for each type of infrastructure from a public investment perspective.

Box 5.3. High-level decision criteria for public investments in digital infrastructure for higher education institutions

Various criteria have been developed by national and international bodies to support effective, fair, and transparent decision-making on investments by public authorities, in a context of constrained resources, and uncertainty about the likely impact of the proposed investments. Based on a review of recent criteria specifications, including the OECD Recommendation of the Council on the Governance of Infrastructure (OECD, 2020[37]), the G20 principles for quality infrastructure investment (G20, 2019[38]), UK guidelines for investment in education technology (Crown Commercial Service, 2022[27]) and the Australasian Council of Distance Education guidelines for benchmarking technology-enhanced learning (ACODE, 2017[39]), the following high-level criteria are proposed to guide infrastructure investments:

1) The envisaged social impact of the infrastructure: the extent to which the infrastructure could contribute to widening equity of participation or completion, and the expected mechanism by which it will do so.

2) The envisaged impact of the infrastructure on the quality of higher education provision: the extent to which evidence exists that the investment will have a positive impact on the quality of higher education. Investments with little or no evidence of impact should receive an accordingly smaller share of resources, but digital investment programmes should also be allowed to promote innovation.

3) The extent to which the infrastructure supports stated systemic goals and objectives: how the investment affects wider policy or institutional objectives.

4) The number or share of users in the higher education system that will have access to or benefit from the infrastructure deployment.

5) The anticipated lifecycle of the infrastructure, regarding both its primary purpose and its potential to be redeployed for other uses.

6) The expected environmental impact of the infrastructure: how the investment might contribute to or detract from sustainability goals.

7) The anticipated impact of the infrastructure on the future cost base of public authorities and/or higher education institutions, in terms of potential future cost savings, or future expenditure for maintenance, support, and upgrades.

8) The adherence of the infrastructure to hardware or software interoperability or data portability standards, to enable integration of the planned investment with existing and future technologies and support the development of data analytics and open data.

9) The extent to which stakeholders and users of the infrastructure have been engaged, as a validation of proof-of-demand for the infrastructure and the fitness of the infrastructure for its intended purpose.

10) The proposed mitigation measures for risks associated with the infrastructure, including procedures for risk-related information-sharing and building resilience against cybersecurity hazards, loss of service, data protection risks and ethical risks.

Investing in network connectivity

Introduction

High-quality network connectivity is essential to digital learning activities, student-teacher digital interaction and the smooth running of administrative and operational systems in higher education institutions. Stable high-speed connectivity facilitates the transmission of audio-visual data for synchronous (i.e. real time) and asynchronous (i.e. self-paced) virtual interaction, including lectures, meetings and tutoring. It also facilitates easy and continuous communication across campuses, contributing to greater operational efficiency. The presence of high-speed network connectivity has been shown to support better learning outcomes (Sanchis-Guarner, Montalbán and Weinhardt, 2021[40]), smoother transition to higher education (Dettling, Goodman and Smith, 2018[41]) and higher online learning uptake in higher education (Skinner, 2019[42]).

Adequate connectivity off-campus and adequate home technologies are particularly important for lifelong learning, which is often done (entirely or partly) online. The COVID-19 pandemic required higher education students and staff to access institutional networks more frequently from their homes or other off-campus locations, greatly increasing focus on the need for high-speed, reliable public-wired networks (including fibre) and mobile data access. In Europe, it is expected that the launch of national infrastructure and digitalisation programmes and new European targets on digitalisation for 2025 and 2030 will lead to rapid acceleration of full-fibre connectivity in the coming years (FTTH, 2021[43]). High-speed connectivity opens opportunities for learners to access education regardless of their location and can increase access to higher education for a wider range of learners.

Large, research-intensive higher education institutions have extensive data transfer demands, requiring much higher link capacity and speed than household broadband connections. Croatia has more than 90 public higher education providers, many with campuses spread across multiple buildings and/or geographic locations. Including students and staff, it is estimated that more than 200 000 regular users need to be catered for by campus connectivity. Institutions' local area networks are usually connected through a single dedicated high-capacity core network, access to which is widely available. Wireless broadband connectivity also ensures full connectivity in large physical learning spaces on campus.

In Croatia, as in other EU countries, there is wide recognition that the socio-economic importance of higher education institutions requires them to have access to adequate high-speed connectivity as standard. The most recent Croatian national broadband plan (EC, n.d.[44]) aims to provide:

> *download speeds of at least 100 Mbps to all households, with the possibility to upgrade to 1 Gbps, and 1 Gbps for government offices and public buildings such as schools and health facilities. 5G networks are to cover all main cities and towns and major highways.*

Recent trends in practice

Trends in off-campus access to network connectivity

While responsibility for off-campus access to network connectivity generally lies outside the remit of public education authorities and NRENs, it is an important factor in learners' ability to access online education opportunities. In terms of general network connectivity, 2021 data for 38 OECD member countries shows different technology mixes across jurisdictions. Copper broadband infrastructure is rapidly being replaced by fibre networks, with fibre now comprising about one third of fixed broadband subscriptions, compared to 12% of subscriptions a decade ago (OECD, 2022[45]).

Deployment of 5G networks in EU countries also advanced rapidly during the pandemic: 5G commercial services are now available in all 27 EU member states, with 62% of Europeans covered by a 5G network in 2021 (up from 30% in 2020) (5G Observatory, 2022[46]). The new sixth generation mobile communication standard 6G is under development. Although unlikely to be widely deployed until 2030 (ABI, 2021[47]), 6G is set to substantially expand higher education institutions' ability to use the most advanced technologies in educational programmes and research, such as eXtended reality (XR) services, telemedicine, haptics and connected autonomous systems (Saad, Bennis and Chen, 2020[48]). Overall, the 2021 European Union Digital Economy and Society Index (DESI) reported that, in 2020, 87% of households had fast broadband network coverage. In addition, 71% had mobile broadband; 99.7% had 4G coverage, 51% had 5G readiness and 14% had 5G coverage; while 59% had fixed Very High-Capacity Network (VHCN) coverage (DESI, 2021[49]).

Despite this progress in coverage and take-up, substantial disparities in connectivity persist. Bandwidth contention within households and on public broadband connections has increased – a challenge not only for students on limited data plans or poor home connections, but also for those who may not have sufficient connectivity available in their area, such as in rural communities. The rural-urban gap in households with fixed broadband subscriptions across EU countries was 12 percentage points (69% versus 81%) in 2021, with 10% of households not covered by any fixed network (OECD, 2022[45]). Data from regulators in 26 OECD countries also indicates a persistent rural-urban divide in connectivity speeds: as of 2020 only 7 out of 26 OECD countries provided access to a high-speed connection to more than 80% of households in rural regions (OECD, 2020[50]).

Trends in on-campus network connectivity

Long haul (Backbone) networks provided by NRENs

Backbone networks are the core network for higher education, enabling higher education institutions to connect to the Internet. In EU countries, NRENs are in most cases the sole providers of fixed and wireless high-capacity Internet connectivity for higher education and research institutions. A common practice is to lease "dark fibre" cables from telecom companies, where it is feasible and cost-effective to do so (OTT, n.d.[51]). Responsibility and provision of equipment for transmitting and receiving data through the cable ("lighting up the fibre") lies with the NREN as the owner or renter of the dark fibre. NRENs that are part of GÉANT (which interconnects 43 European NRENs), provide up to 16 different network services, the most common being IP connectivity, Eduroam (a dedicated inter-WLAN service for the education sector), updated Internet protocols (IPv6) and network monitoring. In 2020, traffic from end-users of NREN networks and services in Europe amounted to over 2 million Terabytes (Tb), over 880 000 Tb more than in 2018, a rise of around 80% in only two years.

On-campus wired networking

On-campus networking includes private wired and wireless, and public networks. Higher education institutions generally run two types of wired network, a core backbone connecting buildings and campus, and networks within individual buildings. In general, the core backbone has similarities to an NREN backbone, often using dark fibre, with in-built resilience in the form of multiple routes between each node. Within buildings, Ethernet continues to be the standard wired networking technology deployed to allow computers and servers to communicate with each other. While higher education institutions were largely in crisis mode during 2020 and some of 2021, it is likely that there was little upgrading or new deployment of Ethernet on campus except to interlink servers where extra capacity was needed, and in new buildings under construction. At the same time, 100 Gbps and even higher speed Ethernet is becoming the deployable state of the art. As of 2022, 100 Gbps switch sales account for more than one quarter of total revenue in the global market (International Data Corporation, 2022[52]).

Traditionally, the default management process for campus networks uses network switching equipment to route data across a network. Such networks are expensive to install, maintain and orchestrate, requiring one or more network switches in every building and software to manage them. Given this complexity, there is a growing interest among higher education institutions in passive optical networks, which use optical splitters instead of network switches and routers. Passive networks can simplify network infrastructure while enhancing resilience (University Business, 2016[53]). At the same time, passive networks may struggle to maintain persistent high performance in certain contexts (Usman et al., 2020[54]).

It is important to note that internal wired campus networks in higher education institutions are often not designed to carry the higher speeds provided by the entry point from the NREN to institutional premises. This means upgrades to the NREN backbone are only useful if internal campus networks are adequately equipped to take advantage of the higher speeds. In reality, campus network upgrades are often carried out using a "triage" approach: as new technology becomes available it is integrated piecemeal into the existing infrastructure, and older equipment is scrapped or redeployed elsewhere.

On-campus wireless

Wi-Fi allows both wireless and wired devices to connect through wireless access to a router box connected to an Ethernet network. In most cases, wireless networks on higher education campuses have evolved primarily more for social than academic purposes, allowing students and staff to stay in touch and access information continuously while on campus. The prevailing trend in higher education institutions is towards enabling wireless everywhere on campus. Wireless is now commonplace in offices, laboratories, classrooms, and public spaces.

Wi-Fi 6, formally called IEEE 802.11ax, is the newest generation for wireless LANs. It can operate in a new 6 GHz band as well as the 2.4 GHz and 5 GHz bands already in common use for wireless LANs. It also introduces some new technologies to help mitigate the issues that come with putting dozens of Wi-Fi devices on a single network (Kastrenakes, 2019[55]). In the coming years, it is likely that Wi-Fi 6 access points will continue to replace existing Wi-Fi 4 and 5 access points across campuses, while campus staff may potentially opt to move the older equipment to student-heavy areas or areas with expected light traffic.

Wi-Fi standards will also continue to evolve: the newest generation Wi-Fi 7 (802.11be) is currently at a nascent stage and is likely to take some years to embed.

The provision of an on- and near-premises wireless networking infrastructure is usually funded using higher education institutions' own resources. In some cases, local authorities may contribute funding or allow access to the local infrastructure. Campus network infrastructures often have to support public Wi-Fi as well as private institution Wi-Fi, increasing complexity and cost. Eduroam is now well-established as a secure global academic network that is made available to staff and students through their higher education institution, including in Croatia (SRCE, 2022[56]).

Principles for public investment in network connectivity

From 2022, Croatia has commenced a substantial investment in upgrading both the CARNET backbone and on-campus networks in order to support improvements in digital maturity of higher education institutions. This includes upgrading the access network, campus network and backbone, as well as the design and implementation of passive and active networks at the campuses of higher education institutions (CARNET, 2022[4]).

It is difficult to find recent examples of similarly ambitious large-scale network upgrades in other jurisdictions. This means Croatia has limited means to learn from the experience of other countries. Regardless, the scale of the planned investment, and its stated intention to cover more than 90% of public institutions, offers substantial opportunities to improve knowledge of the status quo in higher education institutions regarding network connectivity. It also offers Croatia a unique opportunity to harmonise and align standards for network connectivity across institutions, moving campuses further away from "shanty-town" models common across many higher education campuses towards "master-plan" approaches (Jisc, n.d.[57]).

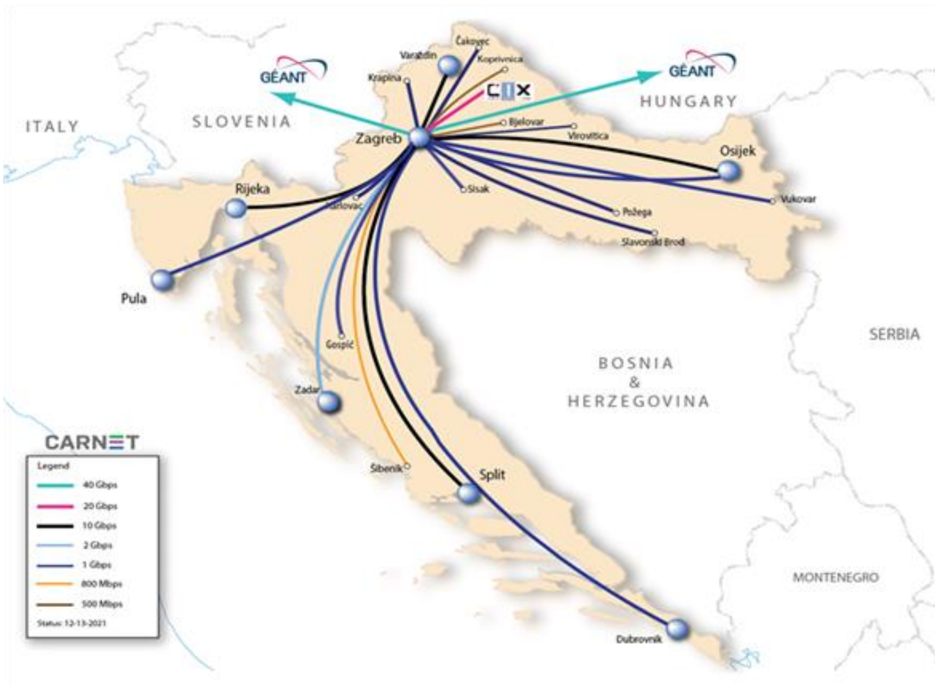
The following sections offer some principles that may serve as the starting point for developing criteria for prioritising networking projects. These principles are intended to be relevant not only for immediate investments, but also for future public investments in network connectivity upgrades in Croatia.

All institutions should have access to a defined minimum standard of connectivity to the NREN backbone, and access to a clear procedure to signal and receive necessary connectivity upgrades

A basic principle often cited to guide public infrastructure investments is that addressing the most pressing deficits and weaknesses should take priority over investments that improve on an already-adequate baseline standard (Missouri DHEWD, n.d.[58]). In Croatia, this would imply that higher education institutions in locations not currently meeting minimum prescribed standards of connectivity to the NREN backbone should be prioritised for upgrades. For example, the current CARNET network connectivity map indicates that some locations may fall short of the current national policy objective of having a minimum 1 Gbps connection per institution (Figure 5.2).

However, this general objective of 1 Gbps needs to be nuanced and balanced against other important considerations, to ensure that upgrades are calibrated for maximum investment value. Active monitoring of traffic across connections can provide the most realistic insight into the needs of institutions. Thus, while the 1 Gbps minimum connectivity standard per institution specified in national policy provides a clear basis for prioritisation, it is also important to consider traffic data in various sites over time as part of the investment prioritisation process.

Figure 5.2. CARNET infrastructure map (2021)



Source: CARNET (2021[59]), CARNET infrastructure, https://www.carnet.hr/carnet/carnet-infrastruktura/

When making decisions about future investments, the minimum baseline of connectivity may also need to be adjusted based on enrolment trends and estimates of the needs at the specific institution site. For example, some institutions responding to the CARNET-OECD digital maturity survey indicated they were likely to move location in the coming years. In addition, some institutions have experienced sharp reductions in enrolments in recent years, which may have implications for network traffic volume and future connectivity needs at their sites.

Various methods may be applied to reach a fair minimum connectivity standard for each site. Many approaches take a “formulaic” approach - allocating a basic amount of bandwidth per eligible person at the campus and adjusting for specific contextual factors such as volume of research activity, or the location of the institution. Alternative approaches could also be applied, based on indicators derived from actual network usage data. Regardless of the specific formula applied, what is most important is to clearly specify the criteria for establishing the acceptable minimum standard and prioritising funding to those institutions that fall below it.

Upgrades to the backbone network beyond the minimum connectivity standard require a method for assessing current and likely future saturation of links

Evidence indicates that bandwidth needs may double multiple times over the lifetime of a network (Cisco, 2020[60]). Monitoring of existing network traffic levels can provide the clearest indications of where current saturation points lie and provide a basis for estimating future bandwidth needs, to pinpoint where future upgrades are most urgently needed.

Estimates of future needs should consider an emerging consensus that distinctions can no longer be drawn between disciplines in terms of their network connectivity requirements. While there were previously substantial differences between disciplines in terms of the use of digital tools, distinctions are quickly breaking down as blended or online learning becomes commonplace in almost all subjects. In addition, with synchronous videoconferencing (Zoom, Teams etc.) becoming widespread during the era of emergency online learning, the “new normal” expectation is for ad-hoc connectivity to be continuously available for online and hybrid meetings and events. Many institution staff reported to the OECD study team during site visits that demand for online and hybrid meetings remains high despite the full return to campus, as it is frequently perceived as more convenient for co-ordinating face-to-face meetings. The widespread use of video also evens out data usage between fields of study, given that video streaming is a much more data-intensive use of network resources than, for example, productivity tools (e.g. Microsoft Office suite).

There is also an increasing expectation across all subjects that students will require specialist software and higher computing power, which may be server- or cloud-based. Similarly, while researchers traditionally in data-intensive disciplines (such as astronomy or physics) tended to make much greater demands on the network than in other disciplines (such as pure mathematics), the increasing use of technologies such as augmented reality and virtual reality in a wide range of disciplines (creative arts, archaeology, medicine etc.) is contributing to evening out these differences. For example, an hour of YouTube video is estimated to require between 0.26 GB (lowest resolution) and 2.7 GB (4K Video) (Wiwatowska, 2021[61]). Zoom and similar online meeting software can require up to 900 MB for an hour’s conference – and more in high-definition (HD) mode (Holslin, 2021[62]), while virtual reality has been estimated to require a connection of up to 600 Mbps (Fridström, 2017[63]; Mastrangelo, 2016[64]).

Any estimation of future network connectivity requirements should account for research activity needs. In some institutions, data traffic linked to research is estimated to take up more than half of all the institution’s traffic. For example, until 2021, Imperial College London had a base load of 10 Gbps for “normal business” (teaching and administration) and 30 Gbps for “research data exchange” (Imperial College, 2022[65]).

Given the demographic context in Croatia, it is unlikely that potential future growth in student numbers would alone lead to substantially increased network connectivity requirements. In addition, the increasingly fluid and flexible nature of higher education provision may naturally lead to well-dispersed loads on the network connection, except for potential surges at certain times of the year (e.g. revision periods before exams). Developing mitigating strategies to plan for unexpected network congestion (such as prioritisation of types of network traffic) may be more impactful than trying to anticipate exact traffic patterns. Network user behaviour on campus, including during the pandemic period, has proven challenging to predict (for example, see (Evans, 2020[66])).

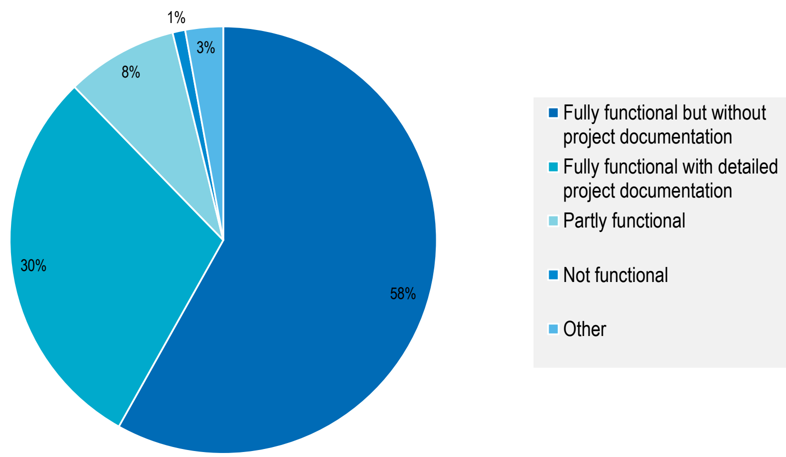
Public investments in upgrading on-campus networks need a clear understanding of the status quo as a starting point

As discussed above, Croatia is currently planning to provide most higher education institutions with network upgrades as part of the e-Universities initiative. Best practice dictates that network upgrades must begin with a full understanding of the current network structure, with a full physical and logical map of each location (Cisco, 2020[60]; Pearson, 2017[67]). A potential concern flagged by responses to the OECD-CARNET digital maturity survey is the pervasive lack of full documentation for on-campus networks. More than half of all respondents indicated that full documentation of their network was not available (Figure 5.3).

Therefore, the national development plan should begin with a thorough assessment of the status quo. CARNET should aim to have a clear understanding of the current physical network infrastructure for each higher education institution before proceeding with proposals for upgrades (and, indeed, network mapping activities are already foreseen in the first stage of the e-Universities project).

Figure 5.3. Functional status of wired local area networks in Croatian higher education institutions

Share of institutions reporting each of the following cases, in relation to their wired local area networks



Source: 2022 OECD-CARNET Digital Maturity Survey of 95 Croatian Higher Education Institutions.

StatLink https://stat.link/204fah

The institution-level infrastructure reviews in the initial stages of the e-Universities project will be essential to ensure effective investment in network upgrades in subsequent phases of the project. However, such infrastructure evaluations also have wider potential to benefit the higher education system in Croatia, through widespread synthesis and sharing of the knowledge learned from the reviews. Accessible syntheses of the current state of on-campus network provision could support the identification of gaps, systemic risks and challenges beyond the remediation measures foreseen by the e-Universities project. As an example, Jisc published a synthesis of findings from 118 infrastructure reviews carried out in the further education and skills sector, highlighting key strategic considerations, best practices, and deficits in the status quo (Jisc, 2020[68]).

Direct procurement and installation of networks as part of a public investment programme has implications for subsequent support and management

In cases where direct provision and installation of on-campus network provision is made, consideration needs to be given to ongoing support and maintenance. Investment plans in network infrastructure improvements should include a concurrent training process for on-site staff to support and maintain the upgraded network infrastructure.

Direct provision and support of on-campus networking is a growing trend in some European countries, referred to as Campus Network as a Service (CNaaS). A CNaaS model can be a solution for institutions with limited on-site IT support capacity. It may be particularly relevant in the current context in Croatia, where many institutions reported to the OECD review team a chronic shortage of trained staff to maintain and support campus networks and IT infrastructure. CNaaS does not necessarily entail deskilling or employment loss for current on-site staff. Off-site management may be used as a complement to on-site management, or to reduce pressure and workload for on-site staff (GÉANT, 2022[24]).

Investments in network architecture should aim to integrate current and emerging best practices for resilience and security

NREN backbones form the main basis for Internet connection in higher education campuses across Europe and beyond. Given their vital role in the daily operations of institutions, it is widely considered to be best practice to make the connection as resilient as possible. The emergent standard for resilience for backbone connections is to ensure that each location has two geographically separated links to the backbone (in this case, CARNET), either directly or indirectly through another site of the organisation. Budgetary and practical considerations may prevent this standard from being fully realised across the higher education system in Croatia. However, ideally the planned upgrades should serve to advance the resilience agenda and limit the extent to which single points of failure are present throughout the system.

Within campuses, upgrades to network infrastructure should also provide increased resilience. Pervasive wireless access on campus, even in wired areas, provides one form of backup resilience in case of failures within the wired network. Other solutions for resilience include the introduction of redundancies in the network topology and adoption of emerging best practices in network Orchestration, Automation and Visualisation (OAV) that support computer-aided reactions to network failures or changes (GÉANT, 2022[69]).

Security is a recurring concern related to digital infrastructure and is becoming ever more important, in a context of continuously increasing threats (ENISA, 2020[70]). For example, in 2022, 92% of higher education institutions in the United Kingdom reported a security breach or attack had taken place in the previous 12 months (GOV.UK, 2022[71]). In the United States, the average cost per organisation of recovery from a ransomware attack has risen to more than USD 1.4 million, with higher education institutions identified as being among the slowest to recover (Sophos, 2022[72]). Cybersecurity across higher education systems will need to be further enhanced in the coming years, given the rising incidence of cyberattacks, including ransomware attacks.

A challenge specific to the higher education setting is the tendency for personal devices to be allowed a much greater level of access to campus networks than in a corporate environment, potentially increasing risks. NRENs such as CARNET play a vital role in cybersecurity by providing network monitoring, specialist support when an institution comes under attack, and a vital source of advice and notification, both for taking immediate action and monitoring emerging threats. As investments are made in network upgrades, concurrent investment in cybersecurity will be vital, as will continuous efforts to remain updated with emerging knowledge and advice on cybersecurity.

Campus locations may need to be itemised and prioritised for inclusion in network upgrade plans

Some institutions in Croatia highlighted to the OECD review team an urgent need for internal network upgrades, to replace older cabling and switches that cannot use the full potential of the backbone Internet connection. Changes in user behaviour after the pandemic are also generating more traffic on wired on-campus networks. Institution IT staff in Croatia reported more use of digital technology and connectivity during on-campus lectures, and staff and students are increasingly uploading and accessing data-intensive media on-campus, continuing habits formed during periods of emergency online provision.

In recent years there has been a surge in staff and student personal devices on campus, generating continuously increasing demand for access to campus Wi-Fi networks. A higher education campus also attracts members of the public for conferences, social visits, or open days. This requires facilities to enable Internet access to people who are not registered on their systems. Network managers therefore come under pressure to increase the number of access points and the number of devices that can connect concurrently, including in campus gathering points and public outdoor spaces. As a result, device and access management becomes more complex.

Given these continuously increasing competing demands, and limited available resources, it is likely that some central prioritisation of specific “micro-locations” on campus will have to be carried out by CARNET when making decisions about campus network upgrades. Prioritisations can be made according to the activity being carried out at the campus location, the desire for network access at the location, and the importance of the location for the mission of the higher education institution. Box 5.4 provides an example for prioritising campus locations, based on expert consensus, that could be a starting point for central priority lists.

Areas of campus that cannot be prioritised for network access will need to adapt to available network conditions. Acceptable use guidelines developed by CARNET and integrated by each institution may need to be updated to account for changes in user behaviour in recent years, or to limit some types of usage and traffic that may not be directly relevant to the mission of the institution. In a worst-case scenario, traffic shaping may be required (Froehlich, 2020[73]) to optimise campus network bandwidth by prioritising certain types of traffic, although this may be unpopular with students, and depending on the shaping strategy, raises potential concerns about Internet neutrality (Ofcom, 2010[74]).

Finally, it is possible, in the context of partial upgrades planned and managed by providers external to the institution, that proposed measures are not suitable or attractive to the higher education institution management. The reasons for this may include a lack of compatibility with existing technologies, recent upgrades having already been made using the institutions own resources or concerns about ongoing support for the upgraded equipment. In such cases, given the overall target to provide 90% of public institutions with upgraded infrastructure, institutions opting out of the centrally provided network upgrades could be prioritised for more innovative stand-alone “showcase” projects in other categories of digital infrastructure, such as on-campus technical equipment.

Box 5.4. Example priority list of campus location types for network upgrades

If complete campus network upgrades are not possible, priorities may need to be assigned to different campus locations. The following priority list is presented as a potential starting point for constructing national-level prioritisations for network upgrade locations in Croatia. The priority list should be adapted depending on the type of network installation under consideration (wired or wireless LAN), the available budget and the needs to specific institutions.

Highest-priority campus locations

- student computer laboratory where PCs with suitable monitors are provided on wired connections;
- study areas, often in a library, where large monitors, power and network access are provided
- lecture and seminar rooms;
- multimedia production rooms where academics can create material for the virtual learning environment;
- offices where IT staff, library or multimedia support staff work.

Medium-priority campus locations

- offices for academics where students visit for supervision and advice;
- offices for research staff engaged in data-intensive research;
- offices for administrative staff engaged in admissions, exams, etc.;
- sports halls and centres.

Lower-priority campus locations

- restaurants and cafes on campus;
- general library facilities such as reading areas, stacks, etc.;
- research farms;
- on-campus student accommodation.

Campus locations that will change soon (all types)

Where there are plans to move activities to new campus buildings in the short to medium term, the baseline approach for upgrade plans should be to rely on additional wireless networking rather than installing new cabling infrastructure direct to end-users.

Source: Elaboration based on consensus of external expert opinion. See front matter for more details.

Investing in on-campus technical equipment

Introduction

This discussion of on-campus hardware in higher education institutions covers two main elements: server hardware (used for storing data, software and digital files) and audio-visual equipment for the everyday activities of the institution.

The presence of high-quality, reliable on-campus technical equipment is an important prerequisite for effectively employing digital technology for teaching and learning in higher education. Demand for on-campus technical equipment has been multiplying and expanding into new areas, driven by the pandemic, but also by the deepening integration of digitalisation into all aspects of institution operations. Institutions have reacted to emerging demands and challenges in diverse ways, from investing in more powerful on-campus physical equipment, to virtualisation, depending on the equipment category. This section provides an outline of recent trends in different categories of on-campus technical equipment and proposes some principles to prioritise investments in this category of infrastructure in Croatia.

Recent trends in practice

On-premises server hardware

The most disruptive trend in recent years related to on-premises server hardware has been migration to the cloud. While there is a common perception that on-campus server hardware is increasingly being phased out in favour of cloud services, this has been a slow and uneven process across countries and jurisdictions (Grajek, 2016[75]). Common concerns of institutions related to migration to cloud services include security and losing control of their own infrastructure. IT departments may also be concerned about the implications for local de-skilling, as a result of outsourcing their expertise to cloud service providers. These concerns may diminish as more server applications successfully move to the cloud, and if institutions are able to create a supportive local environment for re-skilling and reorientation of the roles of local staff to work with cloud-provided services.

The availability of high-speed resilient networks in higher education through NRENs removes another concern related to cloud migration – that of ensuring continuous and reliable connectivity. Moving to the cloud means that institutions pay only for the processing and storage they require and can access additional resources such as resilience and instant expansion when required. High-powered computing (HPC) is also increasingly moving to the cloud, including in Croatia, where an advanced computer and data cloud is being developed as a fundamental component of the national research and innovation e-infrastructure, part of the "HR-ZOO" initiative (CARNET, 2021[76]). GÉANT has set up a single market framework for institutions to buy cloud services, allowing European NRENs to collaborate to make clouds accessible. This was achieved through a pan-European tender, with GÉANT acting as central purchasing body on behalf of the NRENs and their member institutions (GÉANT, 2022[77]).

Despite the growth in cloud services, many higher education institutions still host student-facing systems on-premises, implying that recent increases in demand for online services are likely to have translated into a need to upgrade hardware. In general, on-site server hardware provisioning is in a stable mature state, with some emergent common practices related to maintaining its resilience and security. For example, institutions may run duplicate server rooms to provide site-wide infrastructure resilience. Redundancy may also be built into individual servers, depending on how critical the service is to the institution. Virtualisation is increasingly used, on the premise that abstracting the hardware layer from the operating system and applications ensures that a hardware fault does not lead to overall service failure. In Croatia, more than 75% of respondents to the CARNET-OECD digital maturity survey reported using virtualisation in the installation of their servers.

As well as managing resilience, the other main challenge related to server equipment is security. Cybersecurity is one of the most prevalent challenges facing higher education systems globally. Modern security protocols in common use include restriction of server access using multi-factor authentication (requiring two or more methods of verification before gaining access) and virtual private networks (secure connections from remote locations). End-user device management also forms a vital part of the cybersecurity portfolio, with common device requirements including a need for up-to-date operating systems and software, anti-virus software, and allowing remote access to devices in some circumstances.

While cyberattacks are the most common concern discussed publicly, it is also crucial to ensure that resources are allocated for the physical security of on-premises digital infrastructure. Investment in on-premises digital infrastructure entails evaluation and mitigation of risks such as access controls to data centres, CCTV, window guards and alarm systems. Beyond cybersecurity and physical security, other forms of risk must be considered. For example, data centres and servers must be protected from flood and fires.

One key lesson from the pandemic period is that demand can surge overnight. Future infrastructure planning may require greater recourse to server farms which can "surge-scale" (order of magnitude capacity increase) in response to spikes in demand. Such capacities cannot be economically supplied by on-premises server capacity.

Audio-visual equipment

Important categories of on-campus audio-visual equipment commonly found on higher education campuses include data projectors, electronic whiteboards, monitors, cameras and microphones for video conferencing and lecture capture, and specialist devices for voting and providing feedback. Data projectors for computer screens started to achieve dominance from the early 2000s as costs of the equipment reduced and computers became more commonplace in teaching spaces. At the same time, the advent of plasma screen technology (followed by LED and OLED) led to large flat screens being installed in a greater number of rooms across campuses, as these technologies matured and became cheaper. Finally, electronic whiteboards are more usually found in schools rather than higher education institutions (Aflalo, Zana and Huri, 2017[78]). More low-tech solutions such as writeable or glass walls are often preferred for teaching in higher education institutions.

Prior to the pandemic, many campuses had invested in bespoke lecture theatres and other rooms with facilities for video conferencing or lecture capture. Since the onset of the pandemic, institutions have leaned towards investing more in hybrid teaching rooms with built-in microphones and cameras. The underlying technology to serve this need is also rapidly evolving, with bespoke "room specific" systems built on custom hardware being replaced by PC-based systems with affordable high-resolution cameras that can track user movements.

Other supportive developments are also converging to encourage more investment in audio-visual equipment that can support hybrid teaching and learning. These include software that better encodes video to create smoother degradation of sound and video quality when bandwidth drops; new traffic shaping techniques to ensure that audio and video traffic can pass over existing networks with less jitter; instant captioning and transcription built into video conference systems; and improvements in technology for simultaneous translation of speech to other languages.

Croatian higher education institutions expressed a pressing need to improve their on-campus audio-visual equipment, both during the site visits carried out by the OECD team, and in their responses to the CARNET-OECD digital maturity survey. In particular, the survey results indicate a need for audio-visual equipment that can support the use of digital resources during lectures, and equipment that can be used for recording live lectures and hybrid teaching (see Chapter 3).

Finally, an emerging area of growing interest within higher education institutions is the use of advanced audio-visual technologies including augmented and virtual reality. Augmented reality (AR) technology enhances real world settings with computer-generated input, while virtual reality (VR) provides a fully immersive computer-generated environment. AR and VR are useful where physical exercise of an activity is not possible due to cost, availability, safety, or ethical concerns (Futurelearn, 2021[79]). VR is already being used in some subjects such as medicine, where virtual patient simulations are rapidly becoming standard elements for training medical personnel. For example, the University of Zurich developed a VR simulation as an effective and safe method of teaching bronchoscopy (Casso et al., 2017[80]).

AR and VR are also becoming more prominent in arts and humanities subjects. For instance, the University of the Arts in Philadelphia, USA has a centre for immersive media (UARTS, 2022[81]) allowing students and staff to explore technologies such as simulations, stories, performances and digital communities, virtual and mixed reality, performance motion-capture and human-computer interaction across visual and performing arts disciplines. As another example, the Netherlands Film Academy has set up a VR Academy to enable students from the Amsterdam University of the Arts to explore virtual, augmented, and mixed reality (NFA, 2022[82]).

In Croatia, staff in medical, arts and humanities faculties highlighted to the OECD review team a growing expectation to integrate VR and AR as educational technologies for students. Where such technologies exist within faculties, they tend to be allocated primarily for research projects rather than student instruction, except for medicine, where virtual patient software is fast becoming normalised.

Principles for public investments in on-campus technical equipment

All institutions should ideally have on-campus access to a professionally equipped space for developing digital teaching material

In the post-pandemic world, there is an increasing expectation that digitalised teaching materials, including recorded teaching activities, will form an integral part of the landscape of educational provision. As a result, a high priority for public investment is ensuring each higher education institution in Croatia has an equipped space for the creation of high-quality digital teaching materials. This is a fundamental condition for students to have equal access to high-quality digitalised teaching material. Equipping spaces adequately requires not only cameras and microphones for recording presenters and their displays, but ensuring that lighting, acoustics, and soundproofing are appropriate for professional quality recordings, avoiding the need for wasteful repeated attempts to capture material.

Sharing on-campus resources for the creation of digitalised teaching materials also leads to operational challenges to ensure available spaces can meet the demand of the full cohort of staff. Efforts to reduce contention for shared audio-visual spaces may include adopting the pedagogical approaches best aligned with digital rather than in-person provision. For example, there is an emerging consensus that long lectures do not translate well to an online environment. Video recordings used for teaching may be more effective when structured in shorter chunks of 10-15 minutes ((Bates, 2019[83])).

Investment strategies should evaluate and take account of the likely speed of obsolescence, given the rapid pace of development of audio-visual technology

Not all investments in technical equipment will deliver similar long-term benefits. Lower priority should be given to investments in audio-visual equipment where an alternative software-based solution is available, where end-user devices can be used for the same purpose, or where there is a risk that the technology will soon become obsolete.

In recent years, some types of hardware designed for a specific purpose in higher education campuses have been replaced with software-based solutions. Examples include in-class voting/feedback equipment (to run question and answer sessions in a classroom), and room access systems (for checking attendance in classes). While such systems previously required the installation of specific devices, most functions can now be conducted using software (for example, a mobile phone application, or polling and feedback modules, such as the Zoom poll function or the E-Voting plug-in for Moodle (Hadorn, 2020[84])).

Video capture hardware also continues to become smaller and more portable. In recent years, high-quality microphones and cameras have become part of the standard specification of end-user equipment, such as laptops, or are available as low-cost peripheral devices, reducing the need for institutions to invest in central stores of such equipment. As another example, portable USB video capture cards that plug into a range of end-user devices are emerging and will quite possibly simplify and streamline video recording processes in education institutions and beyond (Panopto, 2017[85]).

Governments need a forward-looking approach for investing in digital technologies, addressing not only existing requirements but also anticipating future needs. Existing digital infrastructure may require upgrades to ensure its continued effectiveness, as new software or tools emerge with higher connectivity or computing capacity requirements. Performing horizon scanning and taking stock of technological developments prior to investments can ensure that public expenditure on digital infrastructure is fit for purpose, with a reasonable foreseen period of utility and relevance. Furthermore, investments in audio-visual technologies should be made with interoperability and a potential exit strategy in mind to enable a switch to newer technology as it becomes available. This depends on avoiding overly restrictive contracts or long licensing/maintenance agreements with suppliers.

Some emerging technologies show promise but may not yet be mature enough to prioritise for public investment

As AR and VR use increases on higher education campuses, it is likely that provision and financing will at least partially fall within institutions' audio-visual budgets, due to the need for physical equipment to access the experience. There is currently a considerable cost to deploying AR and VR, including costs for headsets and content creation. Support staff are also often needed to maintain equipment and guide AR and VR experiences for students. These factors explain why AR and VR have so far gained only limited traction in higher education.

Before and during the pandemic, several countries began efforts to integrate advanced technologies such as artificial intelligence (AI)-enabled tools or products in their school systems. For example, Korea has been progressively introducing AI in education since 2018, expanding software education in primary and middle schools, opening AI pilot schools, and developing AI-based models for education (OECD, 2021[86]).

To date, despite recognition of the powerful potential of AI (OECD, 2021[87]), there are fewer examples of AI technologies being systematically deployed across higher education institutions and systems.

Adoption of advanced technologies brings a risk of widening inequalities between students of different backgrounds if these are more often adopted by socio-economically advantaged institutions or students, who may also benefit from better digital infrastructure conditions, and better-prepared instructors, i.e. the so-called Matthew effect (Perc, 2014[88]). Evidence suggests that even for relatively less novel or advanced technologies, equity considerations are critical, as leading-edge technology adoption is higher among the most advantaged families (Bergman, 2019[89]). In addition, AI-based deployments raise several ethical dilemmas within education systems, and, unless managed carefully, may compound an already fragmented learning ecosystem (OECD, 2021[87]).

Together, these factors indicate that some advanced technologies such as VR, AR and AI should not yet be a high priority for large-scale public investment. However, the number of use cases for these technologies is continuously increasing (Educause, 2020[90]; Educause, 2022[91]). In the interest of encouraging and promoting pedagogic innovations, consideration may be given to reserving a small share of public funding for audio-visual equipment for experimentation with initiatives using VR, AR and AI that have potential "showcase" value to the wider system.

Investing in end-user hardware (staff and students)

Staff and students need suitable end-user hardware to access the learning technologies that are now ubiquitous in higher education. Traditionally, the digital infrastructure of the higher education sector has been better provisioned and funded than the school sector. Staff computing hardware is generally provided by the institution, and sometimes enhanced by staff Bring Your Own Device (BYOD) schemes. For students, BYOD remains the default model for end-user equipment, with shared computers usually made available on campus. Computer clusters in dedicated rooms have been standard for many years across higher education campuses, providing students with access to powerful processors, specialist software, Internet access, and printing. With the upward trend of ownership and use of end-user hardware in the home (OECD, 2017[92]), the demand on institutions to provide student computing power has changed but not necessarily diminished.

The prevailing situation internationally is reflected in Croatia, where data shows a lower ratio of on-campus equipment for students than for staff. In most Croatian institutions, there is close to a 1:1 ratio between the number of teaching staff and the number of desktop computers allocated for teaching staff (Figure 5.4).

Recent trends in practice

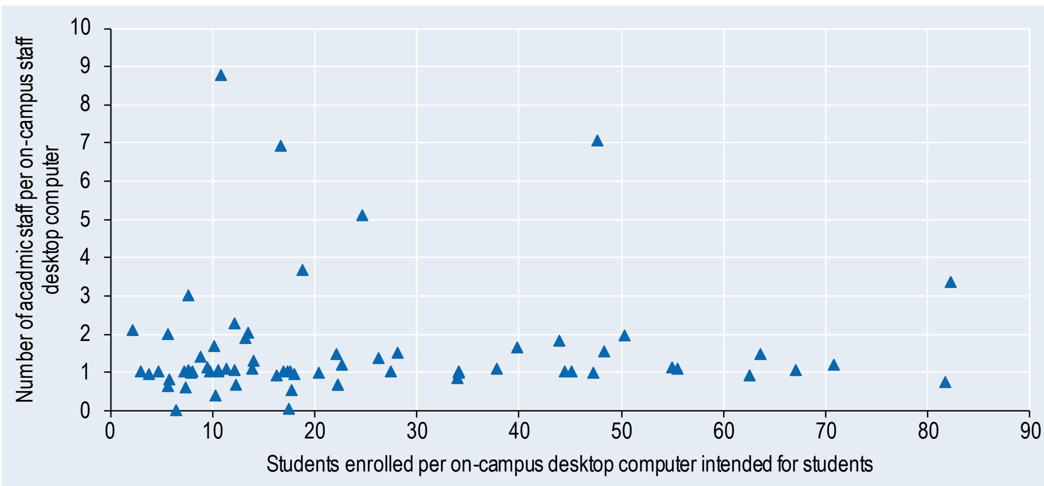
There are few comprehensive cross- and intra-country statistics about access to end-user student devices at home and on campus. In an April 2020 non-probability survey conducted by the European Students Union, among 17 000 higher education student respondents, about 10% reported some difficulties with access to a home computer, and 60% reported some difficulties securing a high-quality home Internet connection (OECD, 2021[19]). In the United Kingdom, a 2020 study of 1 416 higher education students showed that almost one in five students lacked access to a computer, laptop or tablet (Office for Students, 2020[93]). Following the pandemic, it is likely that the share of students without access to a laptop has diminished further.

Various laptop loan or purchase schemes are in operation across countries - some for many years - to ensure students' access to hardware for their studies. For example:

- In the United States, Dakota State University offers full-time freshmen a new laptop, a scheme started in 2004 (Dakota State University, 2022[94]).

- In Scotland, the University of Dundee offers laptop loans to students suffering from financial hardship or digital exclusion (Univeristy of Dundee, 2021[95]).
- To tackle digital divides during the pandemic, the government of Ireland offered a one-off EUR 17 million COVID-19 grant to support disadvantaged higher education students in accessing digital devices and an additional EUR 10 million for access support.

Figure 5.4. Ratio of students and staff to available desktop computers on Croatian institution campuses



Source: 2022 OECD-CARNET Digital Maturity Survey of Croatian Higher Education Institutions. N=69, including institutions who reported greater than 0 computers available for both students and staff, and with outliers removed (i.e. institutions reporting greater than 100 students per desktop computer).

StatLink https://stat.link/kva7qr

Nonetheless, equitable and stable access to digital devices for education purposes varies among students. For instance, survey evidence for the United States in 2020 showed that about one in four higher education students experienced device issues during the pandemic or had to share a device with family members (EDUCAUSE, 2021[96]). BYOD as a substitute for institution-provided equipment also only works if personal devices can interoperate with the main institutional systems. Personal devices might also lack required safeguards leading to privacy and security issues (van der Vlies, 2020[29]). Finally, while most modern devices offer some built-in assistive technology, this may not be suitable for all needs. Although public funding is available in some jurisdictions, there is limited national or international evidence on the availability of end-user devices with assistive technologies suitable for students with additional needs (EPR, 2021[97]).

There is ongoing debate about whether it is more efficient to invest in laptops, desktop computers, or dockable systems using a laptop connected to peripherals such as a keyboard, mouse, and monitor. Traditionally, laptops were heavy and had limited battery life, making them “transportable” rather than portable. Modern laptops are more portable, with in-built peripherals, and have become powerful enough to run more demanding applications. The battery life of laptops has also improved over time, although in practice battery life depends heavily on the use of software programs. A greater presence of laptops on campus has implications for the provision of charging points. Concerns about safety and security may also deter students from bringing higher-specification models on campus.

Desktops have more upgrade options than laptops and are still more cost-effective when more powerful computing is required. Computer labs featuring desktop computers remain ubiquitous across campuses for several reasons, including availability of higher-specification systems, speed of connection, managed access to specialist software and content, larger screens, and security compared with personal devices. Centrally managed student computer clusters also allow institutions to benefit from bulk purchases, which can result in even greater savings. Furthermore, desktop computing is perceived as more ergonomic than using laptops.

There is an implicit lifespan attached to the investment of end-user devices, which is often considered to be in the region of 3-5 years. Investments in end-user hardware at institution level are usually funded through general income and expenditure. Use of procurement frameworks or tenders is commonplace, and contracts may run for several years. Strong repair and warranty contracts are essential for business continuity and are normally included in procurement frameworks.

Principles for public investments in end-user hardware

Public investment in end-user devices with limited value in higher education activities should be avoided

Certain end-user devices have demonstrably less value for higher education teaching, learning, support, and administrative activities, and should not be a priority for public investment. For example, the capabilities of smartphones and tablet-type devices have expanded in recent years and may be useful for accessing certain types of material and communications provided by higher education institutions. Many public authorities have invested in purchasing tablets for students and/or staff in school systems. However, the business case for doing so in higher education systems is less clear. In particular:

- Such devices do not always easily interoperate with the main institutional systems.
- Their lack of computing power means they may struggle with running multiple or resource-hungry applications.
- Not all functions of higher education information systems are suitable for the small screen or touchscreens.
- Smaller screens are suitable for simple forms of content consumption and interaction (for example, notifications or simple quizzes and surveys) but not for all types of content (for example, reading documents in certain formats). They are also generally not easily compatible with content creation tools for educators.
- Storage of and access to documents is required to a much greater extent by higher education students and staff but tends to be much more limited on tablets and phones.

Public investments could therefore focus on equipment that meets an agreed minimum standard for monitor size, computing power and interoperability with other digital infrastructure.

Shared desktops can offer a cost-effective option for procurement at scale, and benefit a large proportion of students and staff

Given the current funding envelope and planned near-term investment of Croatia, it appears unlikely that public authorities will directly purchase end-user equipment for students and staff on a systemic scale, for onward distribution to higher education institutions. In addition, any potential cost savings from mass procurement may be offset by the complexities of gaining widespread agreement of minimum baseline standards for end-user equipment, of establishing criteria for allocations to individual institutions, and of ensuring interoperability and compatibility with diverse existing institution technology.

However, it may be worth assessing the need for, and subsequent funding of, shared computing facilities on campuses where deficiencies in provision have been identified. Despite widespread ownership of personal devices, shared computer labs provide a number of benefits for staff and students, including ensuring access to appropriate computing equipment and software for disadvantaged students, providing guaranteed security and compatibility of equipment, providing access to specialist software, and providing more powerful computing power than many students and staff have on their personal laptops.

In a context where higher education institutions have substantially different levels of equipment, making decisions about the allocation of funding for shared computers is complex. Potentially, an allocation could be made through a formula based on students or staff. Alternatively, allocations could be decided through calculations based on the reported status quo of equipment levels (although the difficulty of collecting and verifying such detailed data would probably create substantial administrative cost).

A more collaborative approach to working with the preferences of autonomous higher education institutions may prove to be more efficient. For example, some higher education institutions may not require investment in shared computing facilities but may need a large investment in audio-visual equipment. The number of institutions in Croatia is limited enough to potentially allow for a structured negotiation process with institutions, whereby institutions could provide assessments of their need for public funding to be allocated to one element of digital infrastructure rather than another.

Beyond direct expenditure, governments could expand collaborative partnerships and collective capacity-building to effectively address equipment gaps

Building partnerships and mobilising knowledge networks are strategies that can support further efforts to bridge equipment gaps across OECD countries. During the pandemic, central governments worked with a range of stakeholders (e.g. schools, municipalities) and private sector actors (e.g. EdTech companies, non-profit organisations, telecom firms) in collective efforts to address inequalities in students' access to digital equipment and tools (Vincent-Lancrin, Cobo Romaní and Reimers, 2022[36]). While many such partnerships were motivated by the pandemic, developing and supporting more stable collaborative efforts could represent a further step in addressing inequalities.

Governments can also play an active role in supporting and establishing platforms for collective acquisition of equipment. As discussed earlier, several European countries directly offer purchasing framework agreements to higher education institutions, and in some cases education institutions are organised into co-operative structures that promote collective capacity-building for digital planning and acquisition (Estermann and Kupriyanova, 2018[98]). For example, in the United Kingdom, a charitable company, the Universities and Colleges Information Systems Association (UCISA) provides members with case studies, surveys, toolkits, best practice guides and benchmark reports to inform the development of digital capabilities. UCISA also includes a Digital Infrastructure Group that advises on technology and services between networks and end-user applications (UCISA, 2022[99]).

Investing in software

Introduction

Higher education institutions deploy a diverse ecosystem of software across their campuses, intended to enhance teaching and learning, and streamline administrative and operational processes. Software in higher education comprises software intended for specific use by an end-user, such as office productivity tools, email, and field-specific software. It also includes central applications for widespread collaborative use across the organisation, such as student and management information systems, Virtual Learning Environments (VLEs), content management systems, software for lecture capture, and software for the development of teaching and learning materials.

Central applications should be a key target for public investment, given their potential for delivering systemic benefits, their utilisation by a large share of actors in the system, and their cost effectiveness. For example, the centrally provided Moodle VLE is extensively used across the higher education system in Croatia, and the OECD review team concluded from interviews with institution staff that it provided a vital resource for institutions during the recent periods of crisis.

Results from the CARNET-OECD survey of digital maturity in higher education institutions indicate different levels of maturity in the Croatian higher education system for the use of different types of end-user software and central applications. Few software application types have reached a ubiquitous "service level" across the system, and some types of software are only at a nascent stage of integration into the operations of higher education systems (Table 5.1).

Table 5.1. Reported levels of digital maturity for common software and central applications in Croatian higher education institutions

	% of respondents reporting at least some level of maturity	% at service level (well-planned and designed to be used by most teachers and students)	% at project level (specific activities involving a group of teachers and students)	% at initial level (experiments at the level of individual teachers)
Virtual environments for live online lectures / courses	99	73	13	8
Learning Management System or Virtual Learning Environment	85	66	6	9
Assessment and grading platform or tool	82	46	11	21
Discussion and/or feedback channels for students	76	39	16	17
Software suites for collaboration and intra-institution communication	76	43	13	16
Software for pre-recording or screencasting lectures	67	12	19	33
Digital tools for the design and development of courses	59	15	12	29
Digital tools that encourage new pedagogical practices	54	9	15	27
Tools / processes that simultaneously support online and personal participation in teaching (hyflex)	41	11	12	16
Learning Analytics	39	11	10	16
Remote exam supervision/ proctoring tools/ services	36	8	8	18
Artificial Intelligence (AI) for personalised learning	19	2	3	13
Blockchain for validating credentials	12	2	4	5

Source: CARNET-OECD survey of digital maturity in 95 Croatian higher education institutions.

Recent trends in practice

End-user software

End-user productivity software is usually provided at an institutional level and generally comprises office suites of word processing, presentation, and spreadsheets. In some cases, it also includes specialist packages for creative media, referencing, and data analysis. In higher education systems across Europe, Microsoft Office 365 has become the dominant office suite, partly because of its widespread use in business, and partly because its educational licensing schemes enable institutions to deploy it at scale, while staff and students can purchase it at an affordable price. Other software packages are more widely used in specific fields of education. For example, Adobe Creative Cloud software is frequently used in the arts and for other creative applications. Most end-user productivity software providers have moved to subscription licensing for both their institutional and private offerings.

In addition to widely used productivity and creativity suites, many specialist end-user software applications support the teaching, learning, research and administrative activities of students and staff in higher education institutions. Examples include software for coding, data science, or specialist individual creative applications. Specialist e-learning content creation tools are often used, such as Articulate (Articulate, 2022[100]) and Adobe Captivate (Adobe, 2022[101]) either as stand-alone programmes or, in some cases, to create material than can be imported into VLEs.

Although some elements of the end-user software market, such as the market for productivity software, are largely stable with few emerging disruptions, several challenges remain. A first challenge is the problem of ensuring interoperability and data portability between different types of end-user software. A lack of interoperability risks creating administrative and operational inefficiencies, increases the potential for vendor dependency, and hampers capacity to develop performance and learning analytics.

Many national and international initiatives exist to support open-source applications as an alternative to paid software, in order to democratise access and reduce reliance on commercial offerings. For example, the EU “Open-Source Software Strategy 2020-23” (EU, n.d.[102]) aims to increase the use of open-source software in government. However, there are many challenges to resolve before open-source software can become the default end-user software type deployed across institutions, including a lack of interoperability with commercial software already in use, and limited access to customer support services. In addition, many types of open-source software are rarely used in business and industry, leading to concerns within higher education institutions about the preparedness of their graduates to use standard industry software when entering the professional world.

A final challenge is the widespread use of “shadow IT”, software used by teachers and students without the awareness or acknowledgement of institution leaders. Shadow IT may cause compatibility issues with the existing infrastructure ecosystem of the institution but can also create knowledge gaps or complacency regarding the effectiveness of institution-provided software solutions.

Central applications

Central applications include email, file storage applications, virtual learning environments, and software for content creation, content repositories and student management systems. Commercial providers tend to offer both email and file storage as part of a suite of services. For example, institutions using Google Suite for Education typically use cloud storage on Google Drive for file storage for both individuals and groups. Institutions using Microsoft Office 365 typically use OneDrive for file storage for individuals and Microsoft SharePoint for file storage for groups. Many higher education institutions have chosen at different times to migrate between commercial providers for this suite of services.

Central repositories are also widely used in higher education as specialised data storage solutions that can categorise and organise types of files relevant to teaching or research. For example, repositories such as D-Space are used by many higher education institutions as a content warehouse for research output (DSpace, 2022[103]). Often repositories are siloed, which limits the value of the stored information and limits transparency, even though transparency is increasingly important for compliance with data protection regulations. A lack of interoperability also limits capacity for creating integrated data warehouses and repositories that can be used to deploy services such as learning analytics.

Several related systems together form the umbrella term “student information systems”. Systems based on Customer Relationship Management (CRM) are becoming increasingly commonplace as higher education providers seek to build a lifecycle approach to student recruitment, timetabling, attendance, progression, and outcomes. Commercial providers of student information system increasingly offer cloud-based solutions, although a large share of higher education institutions maintain on-site installations (Gartner, n.d.[104]).

Finally, video hosting and streaming services were first to the market in higher education, but as lecture capture became more common, systems for previously distinct functions have merged, creating a relatively mature market (Monette, 2019[105]). Modern commercial lecture capture platforms offer integration with VLEs, privacy controls, and in-built capacity for gathering statistics. Many higher education institutions also use free video-sharing platforms (such as YouTube or Vimeo) to share content, while free or subscription services such as Zoom, BigBlueButton, Google Meet or Microsoft Teams have become standard for online meetings and videoconferencing.

Cloud services including Cloud storage, Infrastructure as a Service (IaaS), and Software as a Service (SaaS) have not been ubiquitously adapted across higher education systems. However, as with other elements of digital infrastructure, many central applications have moved to cloud-based provision, reducing the need for higher education institutions to support related hardware and software. Many prominent VLEs, such as Canvas, Brightspace and Blackboard, are already cloud-hosted and supported or rapidly moving toward that model. Moodle, a widely used open-source solution, and the most common VLE in Croatia, was traditionally locally hosted as a default, but many resellers and central providers now offer cloud-hosted versions of Moodle, so that smaller higher education institutions may benefit from Moodle without the need for server hardware.

Cloud services offer the potential to reduce digital divides, benefit from economies of scale, reduce the need to run local IT services, and grant widespread access to a more varied portfolio of resources (GÉANT, 2020[15]). However, the potential of cloud services to bridge inequalities in access relies on fast and reliable network connectivity. Without intervention, institutions with poor connectivity will fall behind in the transition to the cloud and miss out on its benefits. As discussed previously, cloud services also imply a shift in software costs, from a periodic one-off investment to the continuous payment of a subscription.

A core priority at both institution and system level is to pursue greater integration of central systems. Investments in interoperability of central applications potentially have a substantial payoff, in terms of the data that can be generated to support insights and improvements to teaching, learning and administrative processes. For example, learning analytics have the potential to transform current processes for the design and development of educational materials, and improve strategies to promote student learning and engagement.

Governments, higher education institutions and international bodies can help to surmount interoperability challenges by supporting the development and adoption of open-source software and promoting the adoption of open standards for interoperability. For example, the standards developed by 1EdTech (formerly called IMS Global Learning Consortium), cover learning platforms, learning data and analytics, and integrated assessment tools and standards (1EdTech, 2022[106]). VLEs can also ensure interoperability by adhering to common technical standards for e-Learning software products, such as SCORM (Sharable

Content Object Reference Model), which is an industry standard set of technical standards, or the emerging xAPI standard.

Principles for investment

Prioritise investment in software features that meet fundamental needs, rather than features that are unlikely to be widely used

A fundamental risk with the purchase or provision of software is excessive expenditure on digital solutions that are not relevant for user needs or are otherwise unlikely to be heavily used. Commercial providers often develop multi-dimensional products, with increasing cost according to the extent of functionality purchased. Yet, there is some evidence that many advanced features of software packages do not provide added value to users, while potentially incurring a cost for those providing the service.

For instance, VLEs often include learning management functions that enable the transformation of teaching, as well as features that enable educators to manage administrative tasks related to traditional, face-to-face instruction. However, evidence suggests that there is significant heterogeneity in the way academics engage with these features. Academics tend to use VLEs primarily to manage the administration of classes delivered using traditional pedagogy, rather than to modify and enhance their delivery of instruction (Damşa et al., 2015[107]). For example, a large-scale study on the usage of Blackboard software in almost 1 000 institutions found that users exploited only a small fraction of its capabilities. Less than 2% used all of the functionality provided (Whitmer et al., 2016[108]). Another study in the United States found that only 40% of users engaged with advanced features of their learning management systems, despite widespread adoption of the technology (Brown, Millichap and Dehoney, 2015[109]).

Usage patterns of software features and functions may well have evolved during the pandemic period, when users were forced to rely on them to a much greater extent than previously. Nonetheless, investment of finite public funds in software is best made based on demonstrable proof of widespread need and demand for all elements of the proposed software solution.

Consider investing in an open information platform that can be used to share knowledge about usage and user perspectives of educational software tools

Continuous technological advances make it challenging to collect and share information on the diversity of digital tools and software available within higher education systems. For example, there is a lack of data on penetration and use cases for advanced technologies (e.g. AI-based educational tools) across higher education systems, often leaving institution staff to make purchasing decisions based only on information provided by vendors.

Governments can help to improve information flows by supporting the development and maintenance of databases listing available education technology tools/services, along with usage statistics and platforms for user interaction. Creating and disseminating knowledge on the type of digital tools or technology-enabled services that students, teachers, support staff and education administrators rely upon would enable a better assessment of digital divides and digital capabilities across higher education systems.

Prioritise investments that can support greater access and inclusion in higher education

Traditionally, higher education institutions have experienced multiple challenges reaching and supporting students with disadvantages or disabilities (Bong and Chen, 2021[110]). One of the most promising benefits of digital technologies is their potential to reduce inequalities in access to education and create more inclusive education systems (ICF Consulting Services Ltd, 2015[111]).

Technology has been revolutionary in supporting students with special educational needs. For example, specialised text-to-speech software can help learners with motor impairments to write by dictating text. Similarly, integrating behavioural reinforcement capabilities into commonly used software can support students with attention deficit disorders to improve time management, self-organisation, task completion and detail orientation (Mezzanotte, 2020[112]). Digital tools can also facilitate the integration of immigrant or refugee students by, for example, serving as a cultural mediator for learners of different ethnic and cultural backgrounds, for language learning, or as a communication tool (Melstveit Roseme et al., 2021[113]).

One emerging class of software uses equitable design principles to help students from different socio-demographic groups or backgrounds to progress at similar rates. In addition, early warning indicator systems, though nascent and still challenged with accuracy issues and algorithmic bias, show promise in helping educators identify students at risk of failure, while adaptive formative assessment software can support more personalised efforts to enhance student learning (Ganimian, Vegas and Hess, 2020[114]).

In line with Croatia's wider social objectives for higher education, public authorities could potentially invest part of the available funding in software that promotes equity and inclusion in higher education. This could be pursued by identifying central software or add-ins that can support a large share of the learner population, or through funding specific proposals from institutions to pilot and evaluate the effectiveness of innovative assistive software.

The importance of digital competence

Building digital capability must go hand-in-hand with investment in connectivity, equipment and software

Although not included in all definitions of digital infrastructure, digital competence of both staff and students is fundamental to engaging successfully with digital technologies in higher education. Bridging equipment gaps is insufficient if students and staff are not empowered to effectively engage with the technologies provided. Many higher education staff members started their careers at times when the penetration of digital technologies in their workplace was limited or non-existent and have faced difficulties in adapting to the use of emerging technologies that are now vital to their role. Evidence also indicates that younger generations are more familiar with digital tools as consumers rather than as effective users to support their learning; the concept of "digital natives" (Prensky, 2001[115]) is increasingly contested (Gardiner, 2016[116]).

Public authorities have a central role to play in ensuring equitable and widespread access to building digital competence. Such access is crucial to close existing digital divides and ensure that digital education is achievable for all. Citizens need to be empowered to thrive in the digital landscape and supporting students to become more digitally competent is increasingly part of higher education agendas (DESI, 2021[49]). International-level developments are helping to spur national policies. The EU Digital Education Action Plan 2021-27 (EC, 2021[117]) sets out a range of objectives for enhancing the capability of both staff and students, focusing on basic digital skills and competences, digital literacy, computing education, knowledge and understanding of data-intensive technologies such as AI, enhancing levels of advanced digital skills in populations, and ensuring gender balance in digital studies and careers.

A significant challenge lies in determining the most effective methods for evaluating the digital proficiency of both staff and students. This requires not only measuring digital skills, but also assessing the ability of staff and students to make the most of the digital infrastructure available to them. Some NRENs and public bodies are increasingly focused on more structured and strategic approaches to building digital competence. For example, the UK NREN Jisc provides a range of digital capability services including discovery and training tools (Jisc, 2022[118]) and the Jisc Building Digital Capability service (Jisc, 2022[118]).

Croatia has been proactive in creating initiatives to develop digital capability. For example, SRCE provides a training offer to staff across the Croatian higher education system, covering different aspects of e-learning material development and delivery (SRCE, n.d.[119]). The OECD review team found that the work of SRCE is highly esteemed throughout the higher education system, and that future investment in initiatives to build digital competence will benefit from partnership with SRCE as a valued national stakeholder.

Other outputs of this project include a review of international standards, supports and practices for the delivery of high-quality digital education (see Chapter 4), and the guidelines for institutions for developing improvement roadmaps for digital education (see Annex A). Together, these provide a more in-depth analysis of how institutions can build competence for digital education as part of an institution-wide change process.

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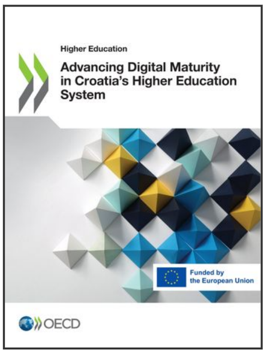
Notes

[1] The digital infrastructure for research in higher education includes text analytics systems, statistical packages, library and bibliometric packages, online access to journals, survey platforms, bibliographic databases and reference management tools.

[2] The enabling factors identified in the EU Digital Education Action Plan include: 1) tackling connectivity gaps; 2) tackling equipment gaps; 3) supporting education and training institutions with know-how on how to adapt and digitise in an inclusive manner; 4) addressing accessibility and availability of assistive technologies; 5) encouraging Member States to develop guidelines for digital pedagogy, drawn from best practice and experience, and upskilling their teachers; and 6) encouraging Member States to foster closer dialogue on digital education between stakeholders in the economy and education institutions.



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