The EU-IoT Framework for Internet of Things Skills: Closing the Talent Gap

White Paper

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The European IoT Hub

Growing a sustainable and comprehensive ecosystem for Next Generation Internet of Things

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ABBREVIATIONS

AI	Artificial Intelligence
AIoT	Artificial Intelligence of Things
AR	Augmented Reality
AWS	Amazon Web Services
CoAP	Constrained Application Protocol
CPPS	Cyber Physical Production Systems
CPS	Cyber Physical Systems
CSA	Coordination and Support Action
DataOps	Data Operations
DevOps	Development and Operations
DDS	Data Distribution Service
EC	European Commission
EU	European Union
EU-IoT	European Union Internet of Things
FPGA	Field-Programmable Gate Array
GDPR	General Data Privacy Regulation
GPS	Global Positioning System
H2020	Horizon 2020
HEU	Horizon Europe
HTTP	HyperText Transfer Protocol
HR	Human Resources
IDE	Integrated Development Environment
IIC	Industrial Internet Consortium
IICF	Industrial Internet Connectivity Framework
IIoT	Industrial Internet of Things
IoT	Internet of Things
IP	Internet Protocol
IPv6	Internet Protocol version 6
LPWAN	Low Power Wireless Network Technologies
MLOps	Machine Learning Operations
MQTT	Message Queuing Telemetry Transport
MR	Mixed Reality
NGIoT	Next Generation Internet of Things
OPC-UA	OPC Unified Architecture
OS	Operating System
OSS	Open Source Software
PaaS	Platform as a Service
PCB	Printed Circuit Board
PLC	Programmable Logic Controller
R&D	Research and Development
RFID	Radio Frequency Identification
ROS	Robot Operating System
SaaS	Software as a Service
SCADA	Supervisory Control and Data Acquisition
UAV	Unmanned Aerial Vehicle
VR	Virtual Reality
WAN	Wide Area Network
WEF	World Economic Forum
WMF	World Manufacturing Forum
WSN	Wireless Sensor Network

1 INTRODUCTION

1.1 Scope and Purpose

The EU-IoT Coordination and Support Action (CSA) is supporting the activities of EU funded R&D projects in Internet of Things (IoT), while also providing resources and services to the wider European IoT ecosystem. These span different areas of IoT development and deployment, including standardisation, reference implementations, open source software implementations, as well as IoT training and skills development.

In skills development, EU-IoT monitors the proclaimed IoT skills gap and develops resources that could help alleviating it. The latter resources include a catalogue of training courses and a series of training webinars on cutting edge IoT technologies. Recent studies have concluded that IoT skills is a catalyst for the accelerated adoption of IoT solutions and for the subsequent growth of the IoT market. This is because the IoT skills shortage is identified as one of the factors that hinder IoT deployments.

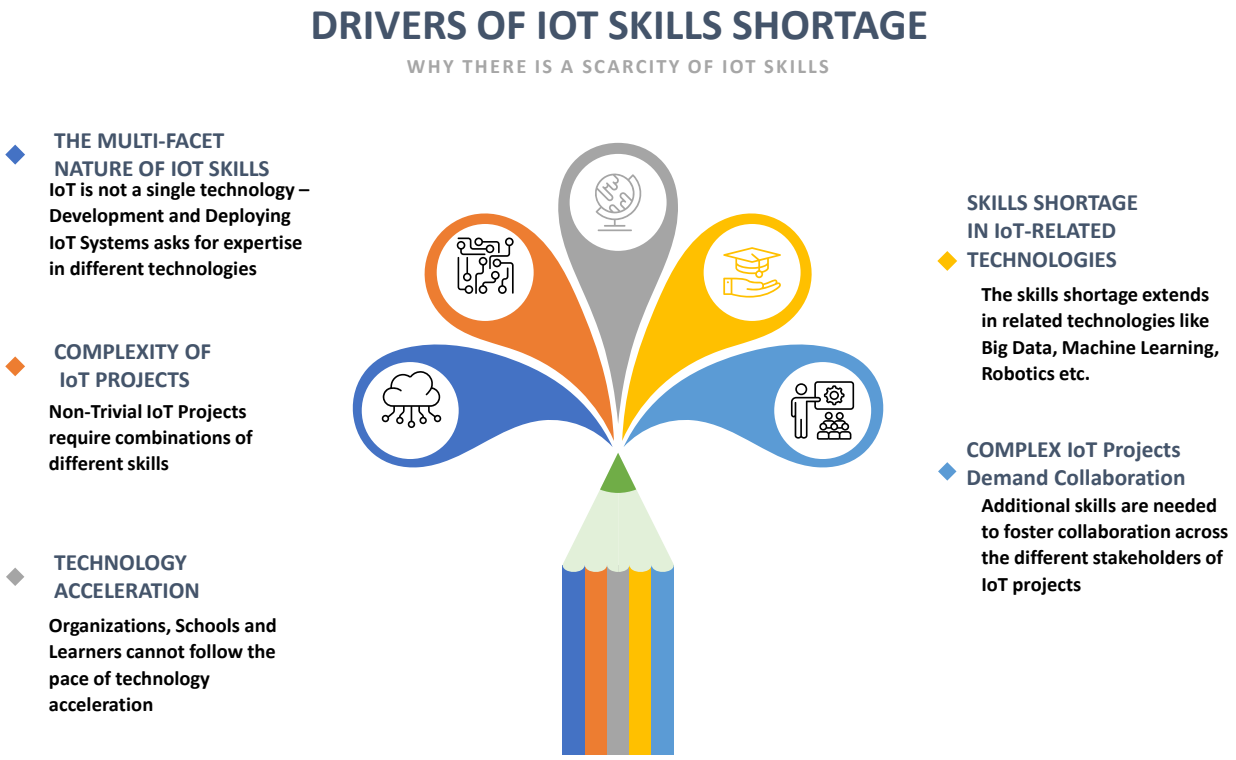

Figure 1: Factors Contributing to the IoT Skills Shortage

The development of solutions to the IoT skills gap is challenging for several reasons, including (Figure 1):

- **The multi-facet nature of IoT skills**: IoT is not a single technology, but rather a computing paradigm that integrates multiple technology solutions such as embedded systems, broadband networks, cloud computing, machine learning and cybersecurity. Therefore, most IoT roles are associated with multiple skills from different technological areas. Furthermore, many IoT skills profiles ask for non-technical skills like business development, marketing, and collaboration skills.
- **The complexity of IoT solutions**: During the past decade state of the art IoT solutions

have increased in scale and sophistication. IoT solutions are no longer a matter of connecting one or a few devices to a network. Rather they comprise multiple technology infrastructures, which have diverse development and deployment requirements. Tacking this complexity asks for IoT professionals with multi-disciplinary profiles and different skillsets that go far beyond the basics of IoT systems.

- **The unprecedented technology acceleration**: Digital technologies are evolving in a rapid pace, which drives a fast-changing IoT landscape. For instance, most IoT-related EU-funded projects cope with technologies like edge intelligence, federated learning, and the tactile internet (e.g., Augmented Reality (AR) and Mixed Reality (MR)). Some of these technologies were hardly available few years ago, while other were not mature for enterprise use. This creates a very dynamic IoT landscape, while makes it very difficult for skills development activities to keep up with the evolution of the state of the art.
- **The skills shortage in related technologies**: As already outlined, IoT projects require skills in cutting edge technological areas like ML (Machine Learning), AI (Artificial Intelligence), and cybersecurity. Each of these technology areas is experiencing its own skills shortage as demand for skilled workers in these areas is skyrocketing. This makes it very difficult to properly staff complex IoT projects.
- **The need for collaboration in IoT projects**: Successful IoT deployments are all about collaboration between different stakeholders and business actors. Hence, they bring together inter-disciplinary and multi-disciplinary expertise, which can be hardly found in modern IoT teams.

Considering these challenges, the present whitepaper aims at shedding light in the IoT skills shortage issue, while at the same time introducing EU-IoT tools for alleviating the problem. Specifically, this whitepaper has the following objectives:

- To review and present the wide array of different IoT skills needed for the development, deployment, and operation of modern IoT projects.
- To review and present how different IoT skills can be clustered in meaningful IoT skills profiles, notably the profiles that are currently high in demand in the global job market.
- To introduce the EU-IoT skills framework, which includes a taxonomy of IoT skills and serves as a basis for defining skills profiles, education activities and learning paths.
- To present the results of the EU-IoT skills survey, which involves over 100 experienced IoT professionals in the specifications of the IoT skills that are currently highly demanded in the market.
- To explain how the EU-IoT skills framework and the EU-IoT catalogues of training courses can drive the specification of learning paths for popular IoT skills profiles. A set of simple, yet practical examples in this direction are presented in the following sections.

1.2 IoT Skills and the Future of Work: The Context

The development of IoT skills in the scope of this paper considered in conjunction with wider developments for the future of work. Despite the COVID19 pandemic outbreak, the key characteristics of the global skills landscape towards the future of work remain unchanged. Specifically:

- **Most organisations worldwide are faced with significant skills gaps,** which asks for frequent reskilling processes. In a recent WEF survey [WEF 2020] the participating companies pointed out that they expected approx. 40% of their workers to need reskilling every six months. The same survey identifies the technical skills that are currently high in

demand by companies, which include IoT. Moreover, the importance of non-technical skills like active learning and flexibility is stressed. This is the reason why we have accounted for non-technical skills in our skills surveys.

- **There is a steady shift towards digital processes, as companies are accelerating their digital transformation.** During the pandemic employers have been increasingly using the digital tools for collaboration and team building. Moreover, they have scaled up their remote work practices.
- **Employers acknowledge the need to intensify their investments in human skills development**. Most importantly, they are willing to undertake such investments despite the economic downturn of the last couple of years.
- **Organisations are accelerating the pace of technology adoption**. This increases the demand for skills in areas like IoT, AI, robotics, and cyber security. It is also one of the main drivers of the demand for IoT skilled workers.
- **The future lies in the automation, as by 2025 the time spent on current tasks by humans and machines will be almost equal.** At the same time, the current landscape in the job market will be significantly disrupted, as: (i) Technology adoption and use will obviate the need for some of the current job profiles; (ii) There will be higher demand for some other job profiles; and (iii) Some companies will hire contractors for specialised tasks. Likewise, many companies will see and implement changes in their locations, the value chains where they participate, as well as the technologies they adopt.

Our taxonomy of IoT skills takes into consideration the context of the future of work and related trends. We consider technical skills for IoT systems and applications, including skills associated with the future of work. Specifically, we do not only consider skills required for the development and implementation of IoT systems, but also IoT skills required for users of IoT systems. Likewise, we address complementary skills (e.g., soft skills) that are important for the development of IoT projects, products, and solutions as part of a multi-disciplinary and inter-disciplinary approach to IoT skills development.

1.3 Methodology and Structure of the Paper

To produce the present whitepaper, we leveraged a multitude of methodological instruments, including:

- **Desk Research on IoT skills and skills profiles**. We collected and reviewed a rich set of articles, studies, surveys, and whitepapers about IoT skills, as well as IoT-related job posts. This review led to the identification of the most popular and high in demand IoT skills.
- **An IoT Skills Survey based on a proper set of Questionnaires and the Analysis of the Findings**. We structured a survey that listed some of the most popular IoT skills. Accordingly, we administered the survey to IoT-related professionals, including Human Resources (HR) professionals. The analysis of the responses led to the identification of the popularity of the various IoT skills, which can be used to drive the specification of popular IoT skills profiles.
- **Clustering of IoT skills into IoT Skills Profiles**. We illustrated ways for clustering individual IoT skills into entire IoT skills profiles. The clustering took advantage of the EU-IoT skills framework and of the skills survey.
- **Construction of Learning Paths using training resources of the EU-IoT Training Catalogue**. We provided examples of learning paths that lead to the acquisition of the IoT

skills mandated by certain skills profiles. In the scope of the examples, courses and learning resources from the EU-IoT training catalogue were used to indicate the learning path.

The rest of this whitepaper is structured as follows:

- Section 2 reviews IoT skills and IoT skills profiles based on our desk research findings.
- Section 3 introduces the EU-IoT skills framework as a taxonomy of IoT skills with proper categories and sub-categories.
- Section 4 illustrates the main findings of our IoT skills survey regarding the relevant importance of the various skills that comprise the EU-IoT framework.
- Section 5 presents learning paths that lead to some of the most important IoT skills profiles, along with some recommendations for IoT skills development. It also illustrates how interested parties could benefit from the EU-IoT Skills framework and the EU-IoT training catalogue.

2 A SHORT REVIEW OF IOT SKILLS

IoT education and skills are considered a catalyst for the adoption and growth of the IoT computing paradigm. At the same time, IoT skills are considered important for the development, deployment, and adoption of a range of related technologies such as AI (Artificial Intelligence) and CPPS (Cyber Physical Production Systems) in the context of the fourth industrial revolution (Industry 4.0). Furthermore, industrial workers must develop IoT skills, given that the IIoT (Industrial IoT) is an integral element of the digital transformation of most industrial organizations in sectors like manufacturing, energy, oil and gas, mining, and healthcare. IoT skills are important for most jobs and occupations that fall under the broader umbrella of the future of work, which will be characterised by increased automation, transfer of labour-intensive tasks from humans to machines, as well as by increased human-machine collaboration.

The future of work has a very broad scope, as it entails changes in many different jobs across all industrial sectors. It requires a broad range of IoT-related skills, which will be part of different job profiles in various industries. Thus, there is a need for identifying and properly structuring the various IoT skills as part of some IoT skills framework. In this direction, many industrial, educational and research actors have attempted to identify, document, and structure the wide array of IoT skills. The respective classifications had different aims and objectives, such as employment, recruitment, education planning (e.g., [Richert16]), curriculum development (e.g., [Sackey16]), industrial training (e.g., [Piñol17]), reskilling/upskilling, as well as policy development purposes [VanDeursen21] (e.g., industry / university collaboration [Kumar17]).

Several IoT skills reviews focus on technical and technological skills. This is the case for reviews that aim at analysing the technical skills required for developing and deploying IoT solutions. For instance, [Shacklett21] outlines the importance of programming skills (e.g., Python, C, C#, Java Script) and of the knowledge of IoT protocols (e.g., Message Queuing Telemetry Transport (MQTT)) for IoT development. There are also articles that structure technical skills in more complete IoT profiles like hardware designers, embedded firmware developers, backend developers, frontend developers, IoT application developers, automation, and systems integration engineers, as well as data scientists [Dunkels2019]. These roles include profiles that are more general than the scope of IoT applications (e.g., frontend/backend developers). However, IoT's technical jobs and profiles are not limited to hardware and software development. They also cover additional roles like IoT engineers, IoT architects, and IoT researchers [Hiter21].

Nevertheless, the pure technical view of IoT skills is narrow-minded. This is evident in policy related studies (e.g., [Kritikos21]), including the European Skills Agenda [COM(2016)381-2016] i.e. Europe's plan to help individual and businesses develop more and better skills. These policy studies underline the necessity of complementary skills such as soft skills. The latter are considered important both for building IoT and automation systems and for alleviating the potential adverse effects of automation in employment. Typical examples of such skills include problem-solving, creativity, communication, and persuasion.

Acknowledging the importance of non-technical skills, various skills surveys for IoT, IIoT and Industry 4.0 propose thinking, social and other soft skills as critical elements of IoT education or IoT reskilling for industry professionals [Maisir19]. For instance, [Saniuk21] illustrates skills that must be possessed by IoT professionals in managerial positions. Beyond technical skills they identify skills like problem solving, IoT usage, analytical capabilities, communications, life-long learning, management skills, teamwork, openness for change, openness for digitization, openness for automation and more. More non-technical skills are mentioned in [Maisir19], such as self-awareness, self-organisation, interpersonal skills, intercultural skills, social responsibility and accountability, leadership skills, people management, emotional intelligence, negotiation skills, entrepreneurship, and adaptability.

3 THE EU-IOT SKILLS FRAMEWORK

3.1 Overview and Driving Principles

EU-IoT specified its own framework of IoT skills, which structures a set of important and prominent IoT skills in different categories and sub-categories. As such, it can be thought as a simple taxonomy of IoT skills. In the scope of EU-IoT, our IoT skills framework has served the following objectives:

- Executing a survey towards understanding the relevant importance of various IoT skills for the market. The survey was structured based on the project's skills framework. Relevant results are presented in the following session.
- Collecting feedback from the IoT and HR community on the framework towards properly revising the framework. Specifically, as part of the execution of the IoT survey, the project solicited feedback on important IoT skills that were lacking from the survey. This facilitated the revision of the framework based on market feedback.
- Improving the structure and metadata of the EU-IoT training catalogue. Specifically, the EU-IoT framework was used to structure the courses of the catalogue, while enhancing them with metadata relating to the IoT skills that each of the courses' support.

The EU-IoT framework has been developed based on the following principles:

- **Support for technical and non-technical skills**. The framework addresses technical and technological IoT skills, but also non-technical soft skills that relate to IoT skills profiles and roles.
- **Consideration of standards based IoT stacks in the classification of IoT technical skills**. The framework structures the various technical IoT skills in-line with layered taxonomies of IoT technologies, such as the layers of standards-based IoT stacks like the stack of the IICF (Industrial Internet Connectivity Framework)[1].
- **Classification of non-technical skills**. The framework structures the complementary non-technical skills into various categories such as legal, business, marketing, and social skills.
- **Extensibility**. The framework is destined to provide a way for structuring the various IoT-related skills. However, it provides no exhaustive list of available skills. Interested parties can extend the framework with more skills, while retaining its structure.

3.2 Top Level Categorisation of IoT Skills

The framework classifies IoT-related skills into four broad categories, namely:

- **IoT Technical and Technological Skills**: This category comprises skills related to IoT technologies, including skills required to develop, deploy, and operate IoT systems. It aims at providing a broad coverage of the very rich set of technologies that are currently associated with IoT systems.
- **Management, Marketing and Regulatory Skills**: This category comprises marketing and management skills that fall in the realm of IoT product and service development. It also

[1] The IICF taxonomy has been also used to structure the open source projects in EU-IoT's relevant whitepaper [Soldatos21]

includes regulatory related skills such as GDPR (General Data Privacy Regulation) related skills and ethics related skills.

- **IoT End-Users and Operator 4.0 skills**: This category consist of skills required for using and operating IoT systems in various sectors of the economy with emphasis on industrial sectors.
- **Social and Soft Skills**: This is the class of soft skills that are important for the development, deployment, operation, and use of IoT systems. It includes popular soft skills like teamwork, lifelong learning, and collaboration, which have clear relevance for IoT professionals as well.

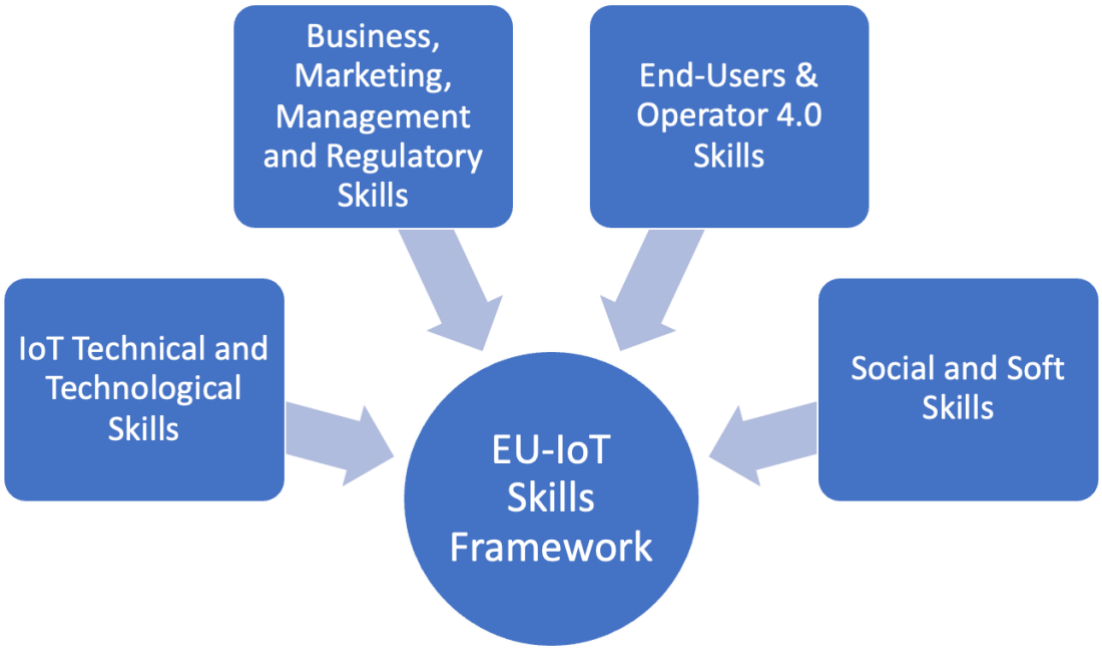

Figure 2: High-Level Taxonomy of the EU-IoT Skills Framework

Each of the four skills categories comprises a rich set of IoT skills, which are structured in sub-categories. The structuring of the various skills provides a sound basis for understanding the types of skills needed for successful developing, deploying, operating, managing, and monetising IoT systems. Hence, the various categories provide a good coverage of the various types of IoT skills. Nevertheless, the listed skills provide by no means an exhaustive coverage of all the available IoT skills. As already outlined, interested parties can enhance the framework with more skills by expanding the list of skills that belong to the various (sub)categories.

3.3 The Four Categories of IoT Skills

3.3.1 IoT Technical and Technological Skills

The IoT technical and technological skills are further segmented to the following sub-categories:

- **IoT devices skills**: This subcategory comprises skills associated with different types of internet-connected devices. Specifically, it includes skills associated with sensors,

actuators, DSP (Digital Signal Processing), FPGAs (Field Programmable Gate Array), the GPS (Global Positioning System), PLC (Programmable Logic Controllers), WSN (Wireless Sensor Networks), ad-hoc networks, RFID (Radio Frequency Identification) devices and more. Each one of these skills corresponds to expertise regarding the structure, the computational capabilities, and the networking functionalities of IoT devices.

- **Smart objects skills**: This subcategory complements device-level skills with additional skillsets that correspond to more complex and sophisticated smart devices such as Cyber-Physical Systems and UAVs (Unmanned Aerial Vehicles). In the context of the EU-IoT skills framework, these more sophisticated devices are conveniently characterised as smart objects. The rationale behind distinguishing smart objects from the rest IoT devices lies in their sophistication, which asks for special skills in developing, deploying, and operating them.
- **Networks and Connectivity**: This part of the IoT technical and technological skills comprises skills associated with various networking and connectivity technologies that support IoT deployments. Our list of skills in this sub-category include the most popular networking protocols and connectivity technologies for IoT systems such as Wi-Fi, Bluetooth and Low Power Wide Area Network (LPWAN) technologies. It also comprises various mobile networking technologies like 4G, Long Term Evolution (LTE), 5G and 6G networking technologies.
- **IoT Protocols**: This subcategory comprises skills associated with various IoT connectivity protocols such as MQTT, Constrained Application Protocol (CoAP) and Data Distribution Service (DDS). These skills are essential to the development and deployment of IoT systems, since they abstract the transport of IoT data for the device to the applications that consume the data.
- **Cloud/Edge/Mobile Computing**: Cloud computing, edge computing and mobile computing related skills are important to the development, deployment, and operation of non-trivial IoT systems, such as systems that integrate data and services from multiple distributed IoT devices. Hence this sub-category is devoted to cloud/edge/mobile computing related skills.
- **IoT Analytics**: This subcategory comprises skills that permit the analysis of IoT data using various technologies and techniques such as ML, DL (Deep Learning) and AI. A wide array of such skills is nowadays important for IoT systems development and deployment ranging from big data analytics to embedded machine learning and TinyML.
- **IoT Security**: Cybersecurity is a critical element for the safe and reliable deployment of IoT systems. Thus, there is a need for security related IoT skills, including for example skills relating to security processes (e.g., risk assessment, pen testing) and to secure operations of various types of IoT devices.
- **IoT Software Programming Skills**: The majority of IoT systems comprise software components. Therefore, software development skills are important for the development of IoT systems and applications. Thus, this sub-category includes the rich set of programming skills that enable the development of the software parts of IoT systems. These skills include for example programming in popular languages like Python, Java and Javascript, as well as in other specialised skills for the programming of IoT devices e.g., robotics programming and Arduino programming.
- **IoT Development Methodologies**: Many modern IoT products and services are developed and deployed over scalable, distributed infrastructure by distributed development teams. Therefore, the establishment of state-of-the-art development infrastructures and employment of proper development methodologies over them are very important for the deployment and operation of successful IoT services. Hence, this

subcategory includes skills associated with mainstream development infrastructures and methodologies that are commonly used by developers and deployers of IoT systems. These infrastructures and methodologies including for example Development and Operations (DevOps), Data Operations (DataOps) and Machine Learning Operations (MLOps) infrastructures.

- **IoT Development and Deployment Tools**: This subcategory includes skills linked to the operation and use of IoT development and deployment tools, such as Integrated Development Environments (IDEs) for IoT development.

These subcategories establish a useful taxonomy of IoT related technical and technological skills, which can be extended with more skills under the specified skills grouping. The specification of these subcategories was partly driven by popular reference architectures that specify the technical building blocks of modern IoT systems. For instance, the devices, networking technologies and connectivity protocols are building blocks of IoT systems specified in the scope of the Industrial Internet Reference Architecture (IIRA) and the Industrial Internet Connectivity Framework (IICF) of the Industrial Internet Consortium (IIC). Nevertheless, skills related to the technical building blocks identified in these reference architectures have been enhanced with skills pertaining to cloud infrastructures, software engineering and project management methodologies. The latter are not specific to IoT systems only, but rather applicable to a broader range of future internet systems. However, these broader skills are important for the development, deployment and operation of cutting edge IoT systems, which is the reason why they have been included in the taxonomy.

3.3.2 Business, Marketing, Management and Regulatory Skills

As already outlined, the inclusion of this category in the EU-IoT skills framework underlines the importance of marketing, management, and regulatory skills for tasks like IoT product development. The category comprises skills clustered in two sub-categories, namely:

- **Business, Management and Marketing Skills**: This is a rather broad category that comprises various business, management and marketing skills which pertain to IoT products and services. For instance, it includes project management, product management, marketing, and financial management skills.
- Legal and Regulatory Skills: This subcategory includes the ever important legal and regulatory skills that are required for developing, deploying, and operating enterprise scale IoT products/services with commercial relevance. Such products must adhere to applicable laws and regulations such as the GDPR regarding data management and data protection. Therefore, the subcategory includes skills associated with IoT Ethics, GDPR and other IoT/AI related regulations.

The list of skills in this category has been purposeful kept shorter than the list of technical IoT skills. This reflects the fact that the development and deployment of IoT systems requires primarily technical skills, yet business, management and regulatory skills are important as well. Like in the case of other categories it is possible to extend the taxonomy with more skills of business, management, and regulatory relevance.

3.3.3 IoT End-User and Operator 4.0 Skills

This category includes skills that should be possessed by the end users of modern IoT systems. It includes the following subcategories of skills:

- **Industrial Automation Skills**: IIoT systems are usually deployed to support, improve, and enhance industrial automation processes in sectors like manufacturing, energy, oil & gas, and mining. Therefore, this subcategory is devoted to industrial automation skills that end-users of IoT systems must possess to successful adopt, use, and fully leverage IoT functionalities. Such industrial automation skills include for example skills associated with the use of legacy automation systems and technologies (e.g., PLC, Supervisory Control and Data Acquisition (SCADA)), as well as with popular industrial processes like quality control and production scheduling. It also includes skills linked to emerging digital tools for industrial automation like digital simulation and digital twins.
- **Asset Management Skills**: Asset management applications are ubiquitous in industrial sectors. They can be found in all industries that must efficiently manage physical assets such as manufacturing, energy and smart buildings. Therefore, end-users of IIoT applications for asset management should have relevant skills including asset programming, intelligent asset management, equipment maintenance, predictive maintenance and more. The EU-IoT framework includes a special sub-category for these asset management skills.
- **Visualisation**: End-users of IIoT applications need to understand and use visualisations of IoT data in industrial contexts. This subcategory is devoted to visualisation skills, such as big data visualisation, AR, MR, VR, design of ergonomic user journeys and more.

Like in the case of the previous categories and subcategories the list of identified skills is representative of end-users and Operator 4.0 tasks rather than exhaustive. Interested parties are welcome to extend the framework with more skills when using it.

3.3.4 Social, Management, and Other Soft Skills

This category signifies the importance of soft skills for IoT systems development, deployment, and use. It comprises the following sub-categories:

- **Thinking Skills**, such as critical thinking, analytical thinking , and complex problem solving.
- **Social Skills**, such as teamwork, interpersonal skills, and professional ethics.
- **Personal Skills**, such as lifelong learning, time management, people management and emotional intelligence.

The relevance of soft skills for the development, deployment and use of technology systems and applications goes beyond the scope of IoT systems and technologies. Their inclusion in the framework aimed at ensuring that they are not ignored when developing or seeking for IoT talent.

3.4 Using the EU-IoT Skills Framework

3.4.1 Stakeholder Groups

The introduced framework is a useful tool for many skills related processes in the IoT ecosystem. Likewise, it can be of great interest to several stakeholders' groups, including:

- **IoT Technology Companies (e.g., IoT vendors, IoT solution integrators)**: These companies can use the framework as part of their hiring and skills development processes. It can serve as a guide for searching for the right talent, evaluating candidate workers

based on their IoT knowledge and skills, as well as structuring training and skills development processes.

- Users of IoT Technology: The framework can help companies that deploy and use IoT systems to properly shape the training and skills development processes of their digital transformation. The latter training processes should put emphasis on developing or attracting professionals with the right IoT skills to ensure that their investments in IoT technology are effective and yield the best possible ROI (Return on Investment).
- Policy Makers: Policy makers can consult our skills framework as part of their policy development processes, notably in terms of educational and training policies. In particular, policy makers could use the framework in conjunction with information about the relevance, the importance and the market demand for each skill, in order to plan effective educational polices that address market needs.

3.4.2 Training, Hiring, and Skills Development Processes

The introduced skills framework can be used to support the following processes:

- **Training Processes**: The framework can support the design and development of training programs that lead to the acquisition of certain key skills or even entire skills profiles. It can also help IoT professionals to select a portfolio of courses for developing or strengthening their IoT skills.
- **Hiring Processes**: HR professionals can consult the framework when implementing hiring processes. Specifically, they can use it to identify the key skills required for specific positions. Moreover, it can help them cluster relevant skills and identify skills interrelationships. The latter are important when trying to hire or form a cohort of professionals that will staff some IoT-related department or project.
- **Skills Development Processes**: HR experts and individual IoT professionals can leverage the framework when designing skills development journeys. For instance, they can use it to cluster multiple related or complementary skills into skills profiles. Moreover, policy makers can take advantage of the framework in their efforts to introduce new skills development programs that address proven skills gaps in the market.

4 THE EU-IOT SKILLS SURVEY

4.1 Survey Identity and Methodology

EU-IoT designed and executed an IoT skills survey which aimed at identifying the IoT-related skills that are high in demand in the IoT market. The rationale behind the design and the implementation of the survey was to identify the IoT-related skills with the highest relevance in the IoT market. In this direction our methodology involved the following steps:

- **Designing the survey in-line with the EU-IoT framework**: The EU-IoT framework was used to structure questions about the IoT skills relevance and importance. Specifically, the survey was segmented into four sub-surveys as per the four top-level skills categories of the EU-IoT framework. Hence, the four sub-surveys concerned technical and technological skills, business and marketing skills, end-users and Operator 4.0 skills, as well as social and other soft skills. Each survey comprised lists of IoT-related skills. Participants were asked to grade the importance of each skill for the IoT market on a scale from 1 (Very Low) to 5 (Very High). Hence, the importance of each skill was indicated by an importance score that was computed based on the total weighted average of the responses.
- **Collecting answers from relevant professionals:** IoT and HR professionals were invited to fill-in the survey. The four different sub-surveys were administrated to different groups of relevant professionals with experience and expertise in IoT skills and IoT projects. For instance, the technical and technological skills sub-survey was answered by IoT professionals with relevant technical experience and expertise, as well as by HR professionals involved in IoT hiring processes. Likewise, the sub-survey on business, management, and marketing skills was answered by a different group that comprised professionals with expertise in IoT marketing and product management. Overall, 70 respondents answered the technical and technological skills sub-survey, 37 respondents answered the business and marketing skills sub-survey, 40 respondents answered the end-users and Operator 4.0 skills sub-survey, and 36 respondents answered the social and other soft skills sub-survey. In total 183 respondents answered the four sub-surveys. The participants come from different industries, including manufacturing, smart cities, energy, agriculture, and security. They also had various profiles and roles including project managers, technical project managers, engineers, data scientists, HR Professionals, developers, architects, researchers, product managers and business development experts. All participants had jobs relevant to IoT and in most cases a strong IoT knowledge and expertise.
- **Analysing the results and identifying the most popular skills**: The results of each one of the sub-surveys were analysed to identify the popularity and importance of various IoT skills according to the opinions of the respondents. As already outlined, the relevant importance of each skill was ranked according to the weighted averages of the responses in the given scale. Skills falling within the same subcategory were directly comparable in terms of their importance and market relevance. For instance, the answers to the survey directly indicate the relevant importance of different device-level IoT skills and of IoT analytics related IoT skills. Skills falling in different sub-categories of the same sub-survey (e.g., IoT networking vs. IoT devices skills) can only be indirectly compared.

Sub-Survey	Number of Respondents
IoT Technical & Technological	70
Business, Management, Marketing	37
End-Users and Operator 4.0 skills	40
Social and Other Soft Skills	36
TOTAL	**183**

Table 1: Number of Respondents in the Four Sub-Surveys

4.2 Analysis of the Results

4.2.1 IoT Technical and Technological Skills Sub-survey

The following figures illustrate the relevant importance of IoT technical and technological skills in the ten different (sub)categories of technical/technological skills of the EU-IoT framework. Figure 3 presents the importance of device related skills. Knowledge and expertise on sensors and sensor networks (e.g., WSN) are considered as most important skills at that level. This is generally expected given their ubiquity in IoT related deployments. Indeed, sensors and WSN span almost all IoT sectors and application areas (e.g., hardware development, software development, middleware development). Other device categories appear less important in general, yet they were perceived very important for professionals in specific industries. This is for example the case with industrial automation devices (e.g., PLC), which were considered very important by manufacturing professionals.

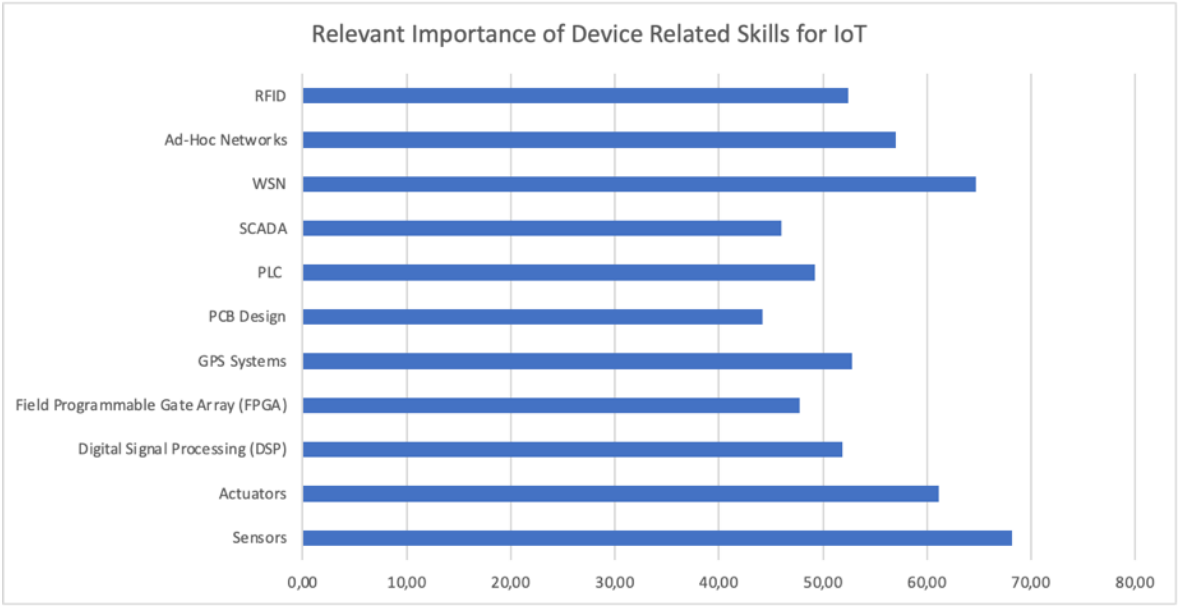

Figure 3: Relevant Importance of Device Related Skills

All smart objects (Figure 4, Figure 5) were perceived as important by the respondents. The most popular and widespread ones (i.e., cyber-physical systems, smart wearables) appear as slightly

most popular in the survey.

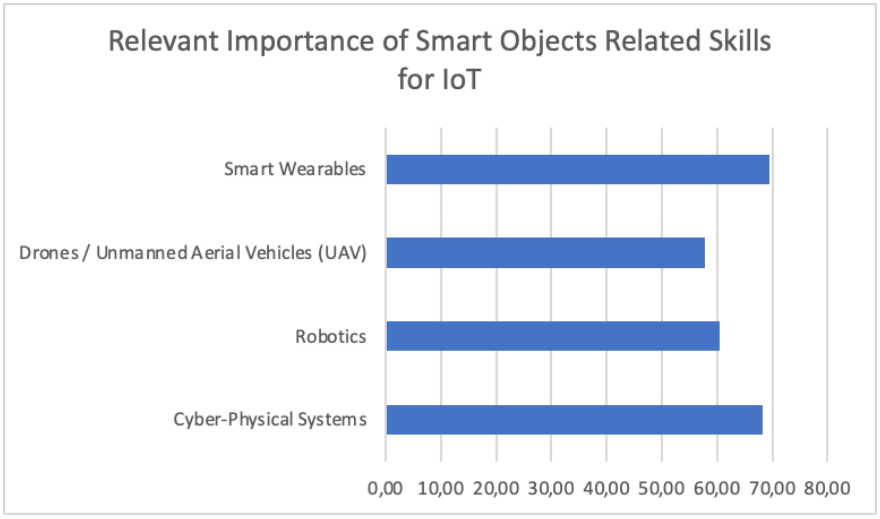

Figure 4: Relevant Importance of Smart Objects Related Skills

Figure 5 presents the survey outcomes about the importance of networking and connectivity technologies. The results seem to follow the evolution of the state of the art. Emerging networking technologies that are tailored to IoT applications (e.g., LPWAN and 5G networks) appear as most popular, along with the most widely used connectivity technologies for IoT applications such as WiFi. IoT connectivity technologies like 6LoPan appear as less important as their popularity is fading.

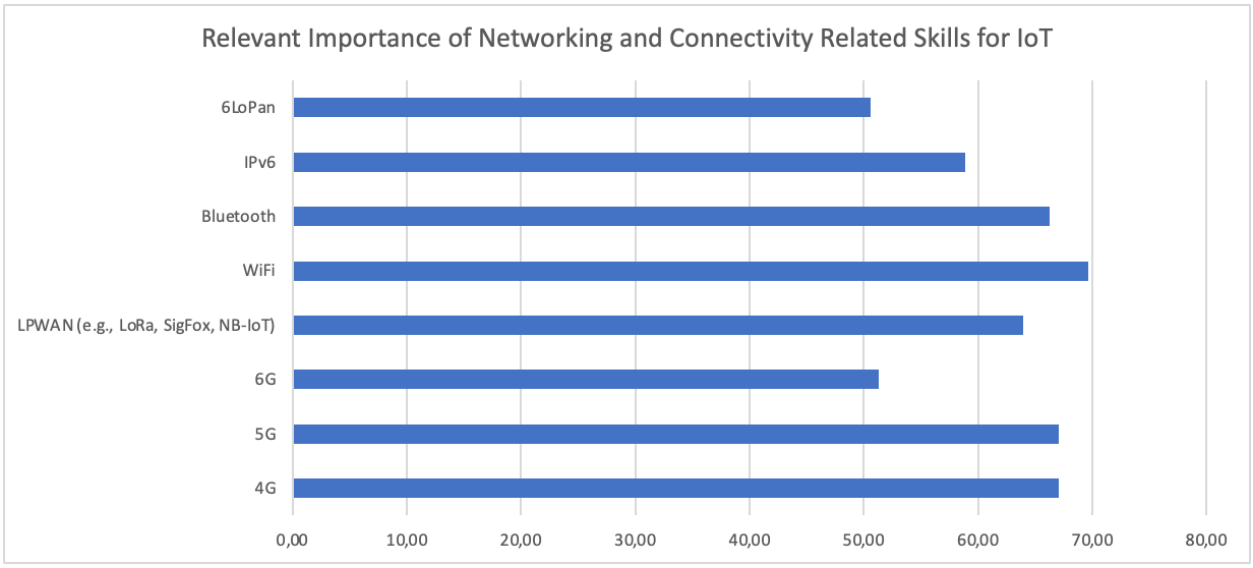

Figure 5: Relevant Importance of Networking and Connectivity Related Skills

Figure 6 ranks skills related to popular IoT protocols. MQTT related skills are ranked as more important than other IoT protocols that are less frequently used (e.g., DDS, OneM2M). Moreover, some protocols rank very high among the responses of the professionals from the sectors where they are used (e.g., OPC-UA is popular within professionals in the manufacturing and other industrial sectors).

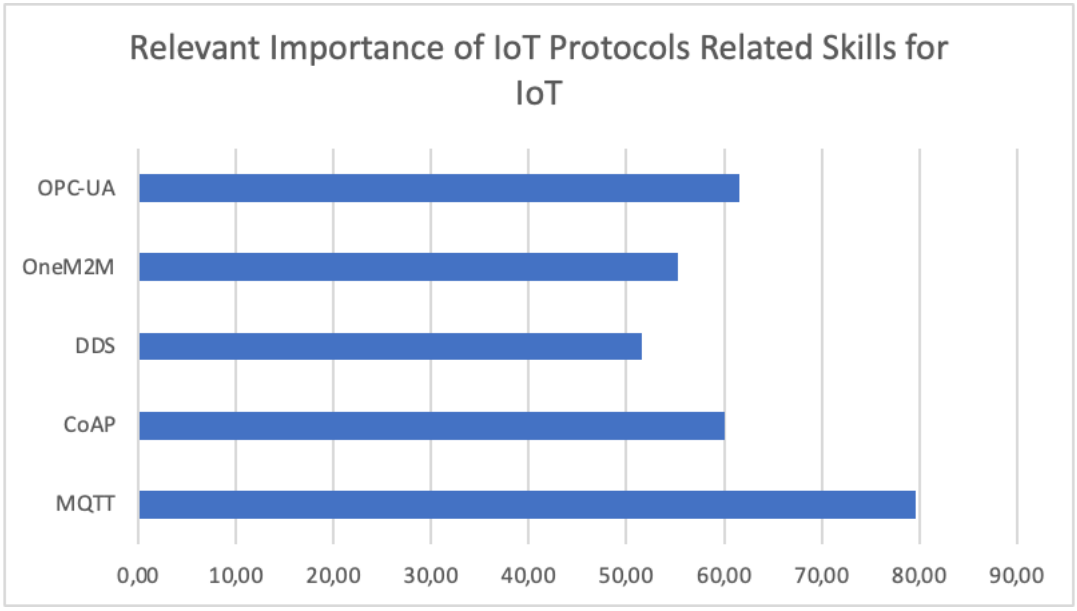

Figure 6: Relevant Importance of IoT Protocols Related Skills

Figure 7 illustrates the IoT skills that are combined with cloud computing and edge computing expertise in a powerful skills combination. This is due to the large number of IoT applications that are integrated in the cloud or follow cloud/edge architectures. Other middleware paradigms (e.g., decentralised IoT applications based on distributed ledger technologies) follow in popularity.

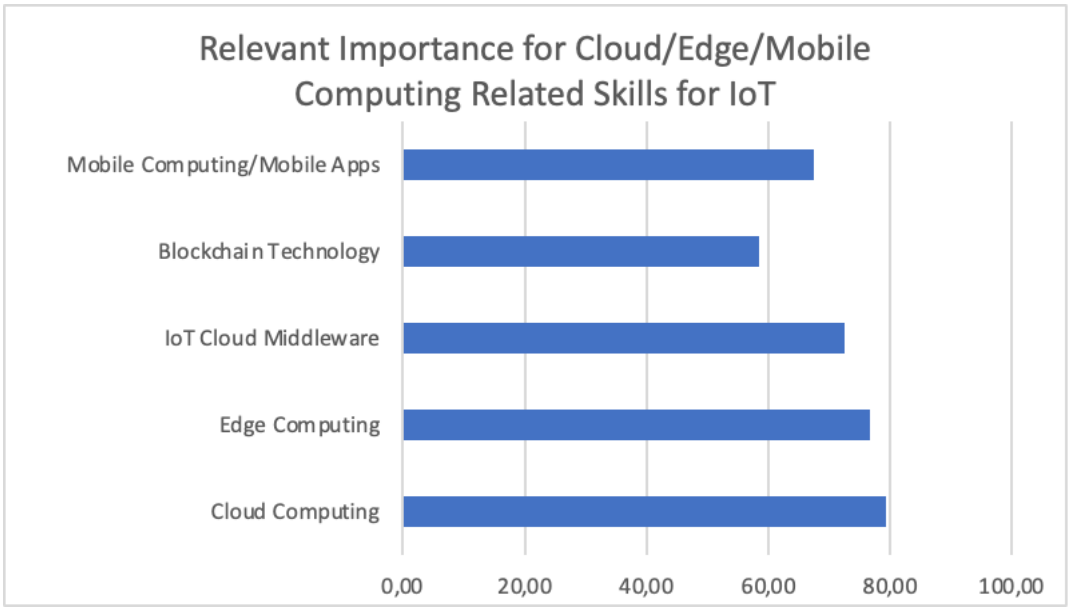

Figure 7: Relevant Importance of Cloud/Edge and Mobile Computing Related Skills

The respondents' opinion on the importance of IoT data analytics technologies (including ML and AIoT related technologies) is illustrated in Figure 8. Mainstream analytics technologies and skills (e.g., Data Science, ML, AI) are perceived as more important than other specialised IoT-related skills (e.g., TinyML). This is probably because IoT analytics paradigms on the device (e.g., TinyML, embedded machine learning) have been around for just a couple of years, whereas conventional ML/AI paradigms are most widespread and popular in the industry. ML is one of the skills with the highest rank across all the different skills of the survey.

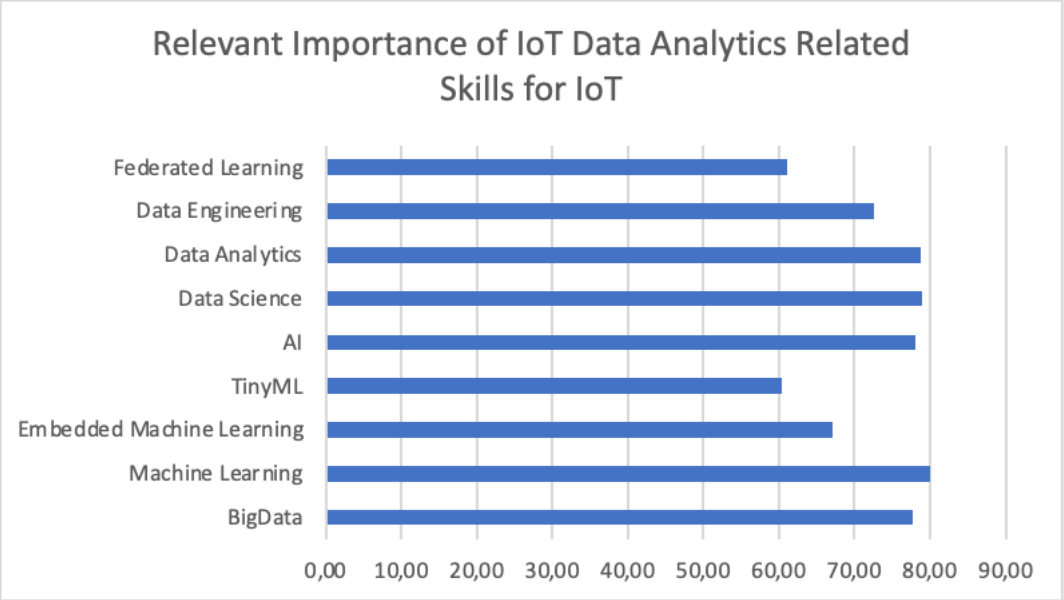

Figure 8: Relevant Importance of IoT Analytics Related Skills

When it comes to IoT, knowledge and skills about the security of IoT assets seem to be more important than more general-purpose cyber-security skills. This is presented in Figure 9, which depicts how respondents perceived different security skills in terms of their importance for IoT development and deployment.

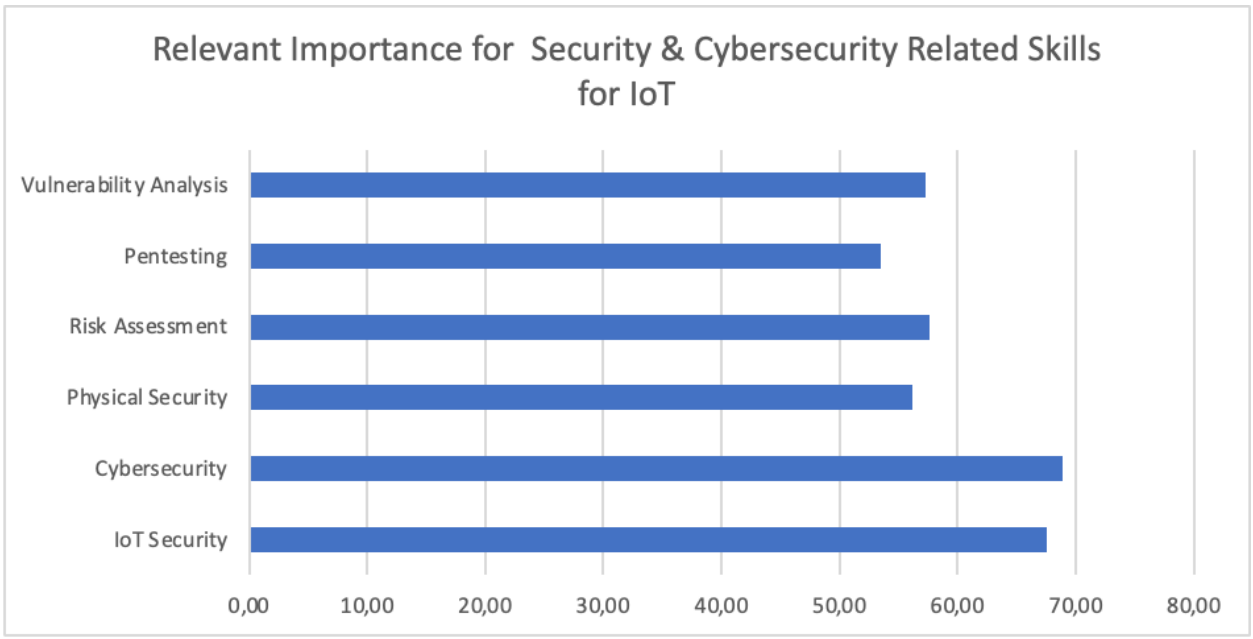

Figure 9: Relevant Importance of Security & Cybersecurity Related Skills

As shown in Figure 10, respondents value general UI/UX skills for IoT application design and development rather than more specialised cyber-visualisations such as VR.

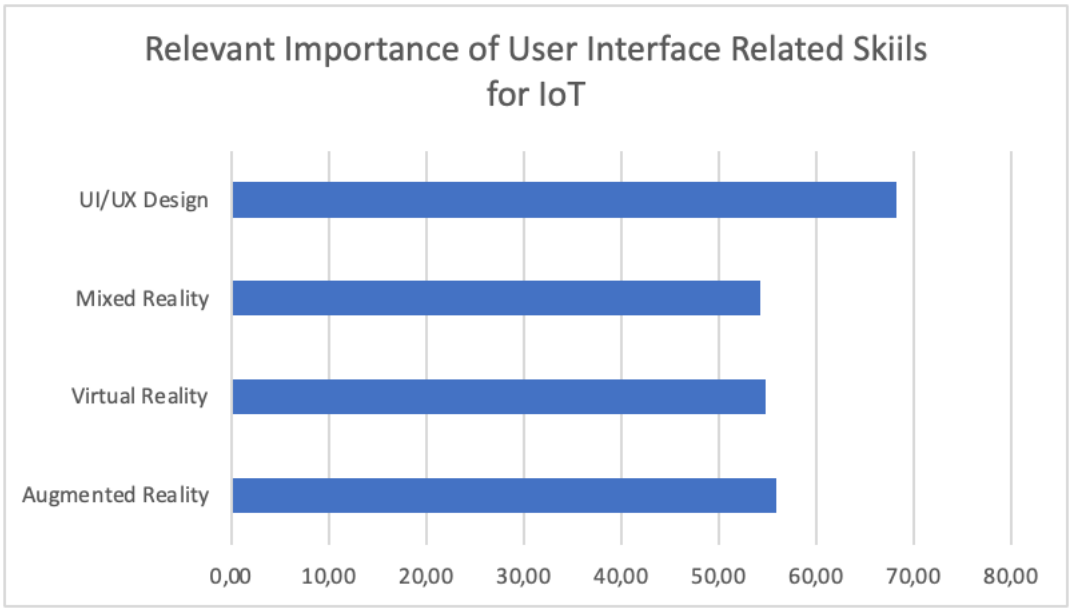

Figure 10: Relevant Importance of User Interface and User Experience Related Skills

Modern non-trivial IoT projects are developed based on agile, iterative methodologies that consider both development aspects and the underlying infrastructure. This is the reason why DevOps skills are deemed as important (Figure 11) and more popular than other methodologies with a more specific scope like MLOps and DataOps.

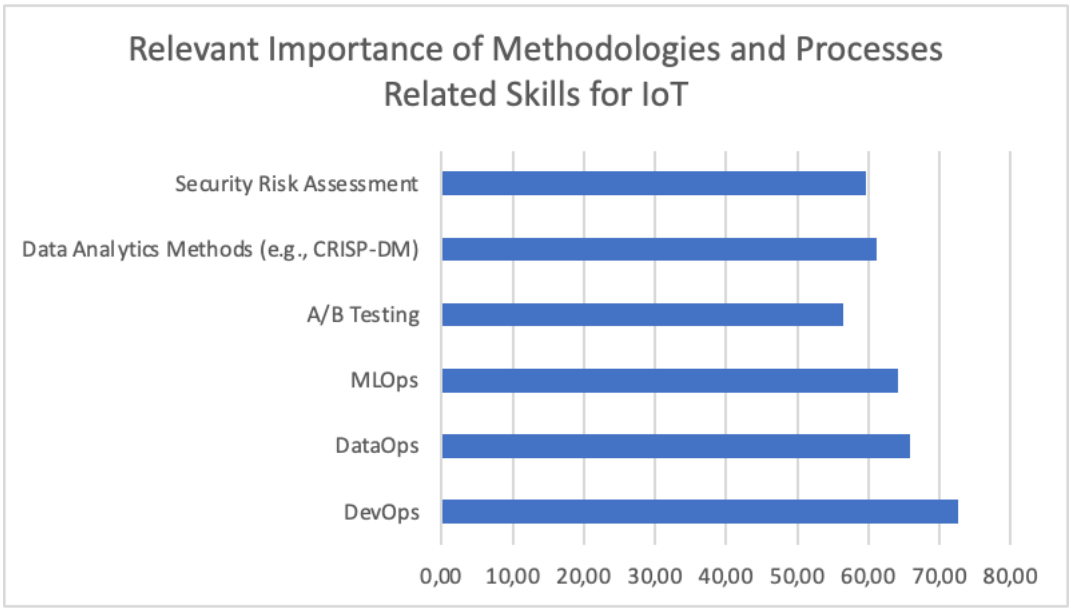

Figure 11: Relevant Importance of Methodologies and Processes for IoT Development Related Skills

Python, Javascript, Java and C/C++ (in this order) are, according to the survey, the most important and popular languages for IoT development (Figure 12). This seems to be a reasonable outcome, given that these languages can be used to program the full stack of IoT systems e.g., from embedded devices to the dashboards and other visualisations of an IoT application.

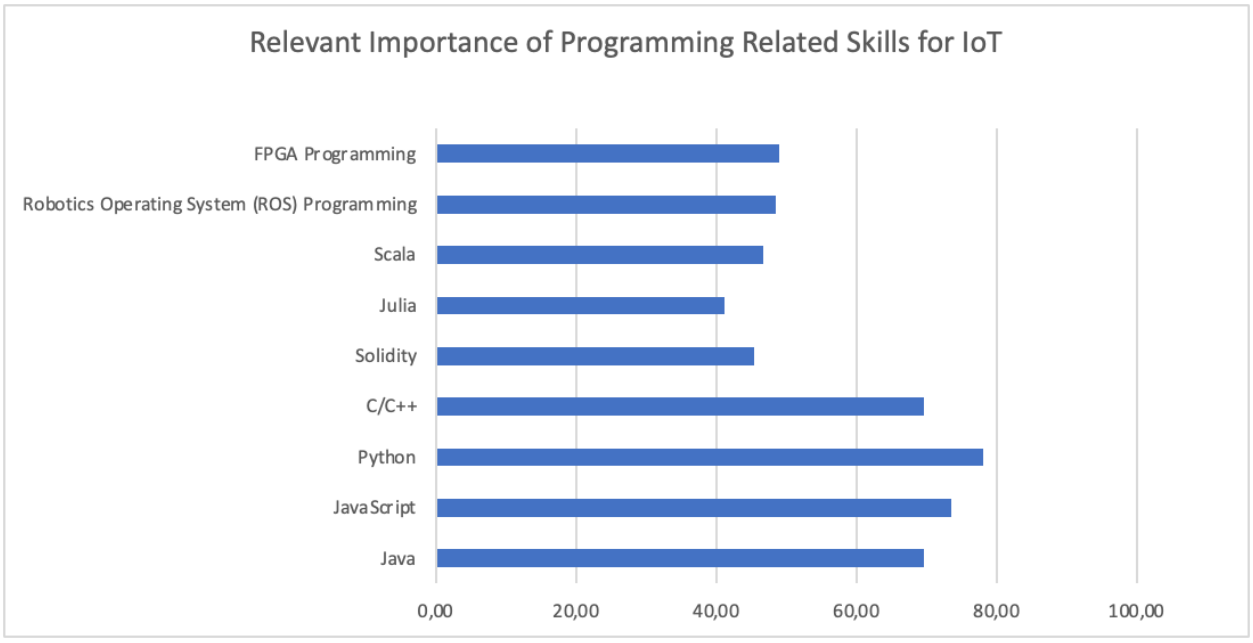

Figure 12: Relevant Importance of Programming Related Skills

Finally, it seems that IoT applications are increasingly developed and deployed in conjunction with modern distributed infrastructure abstraction and workload management technologies like Docker and Kubernetes (Figure 13). This is the reason why these tools are considered important for IoT projects and even more important than specialised IoT tools. Respondents also expressed the importance of integrated IoT development environments in the overall IoT platforms and tools ecosystem. Knowledge of some IDE (Integrated Development Environment) is an important technical skill for certain classes of IoT professionals (e.g., IoT developers).

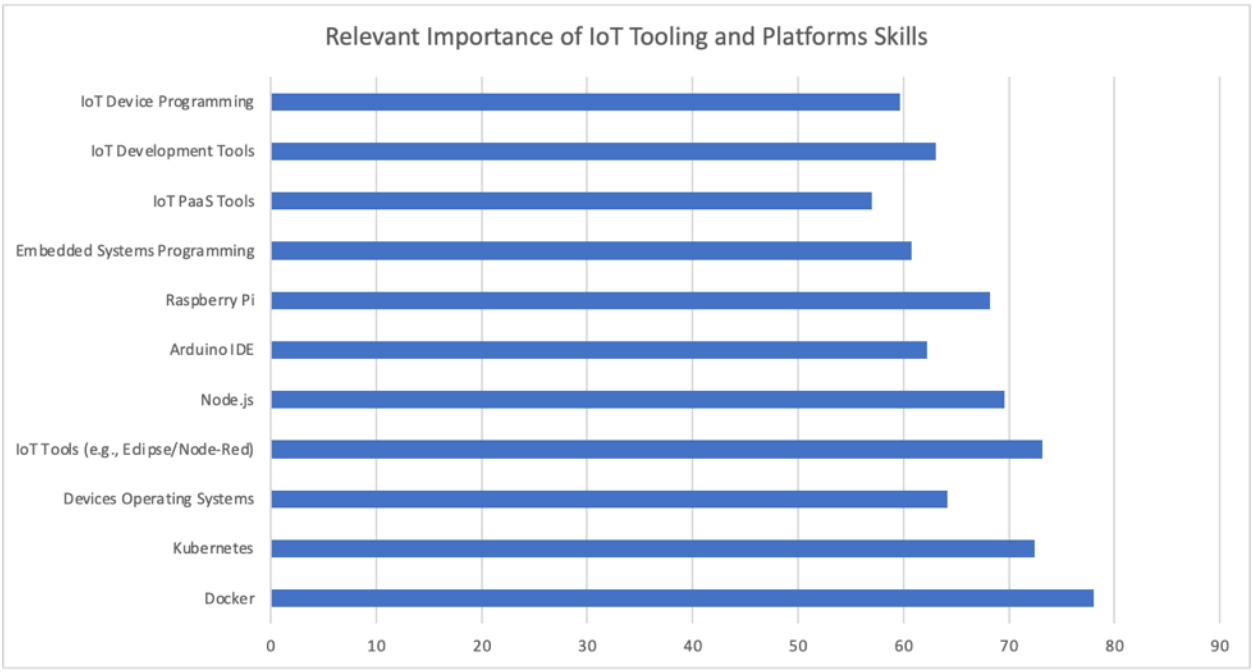

Figure 13: Relevant Importance of IoT Platforms and Tools Related Skills

4.2.2 Business, Marketing, Management and Regulatory Skills Sub-survey

The following figures illustrates the respondents' opinion on the relevant importance of the business, marketing, and management skills of the EU-IoT framework. Figure 14 demonstrates that product management and project management are two of the most important skills for IoT professionals. Both have a rank close to 80%. Marketing and finance related skills have a lower rank.

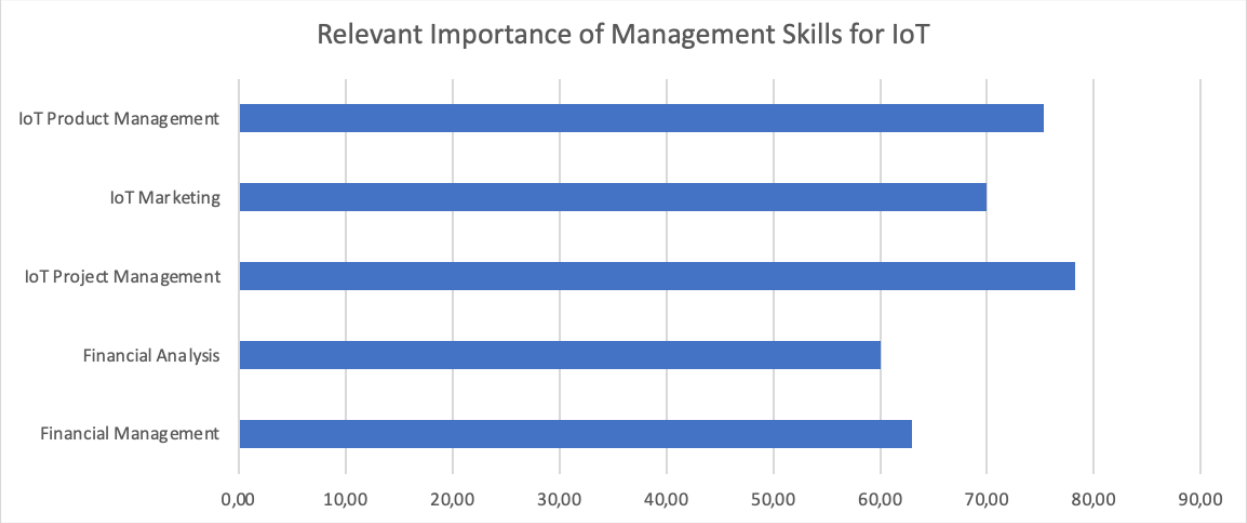

Figure 14: Relevant Importance of Management and Marketing Skills

Figure 15 lists the outcomes of the survey regarding the importance of ethics, legal and regulatory skills. As most respondents were European, GDPR related skills are deemed very important. This is reasonable given that GDPR is a mandatory regulation and that many IoT applications (e.g., healthcare applications) handle sensitive data.

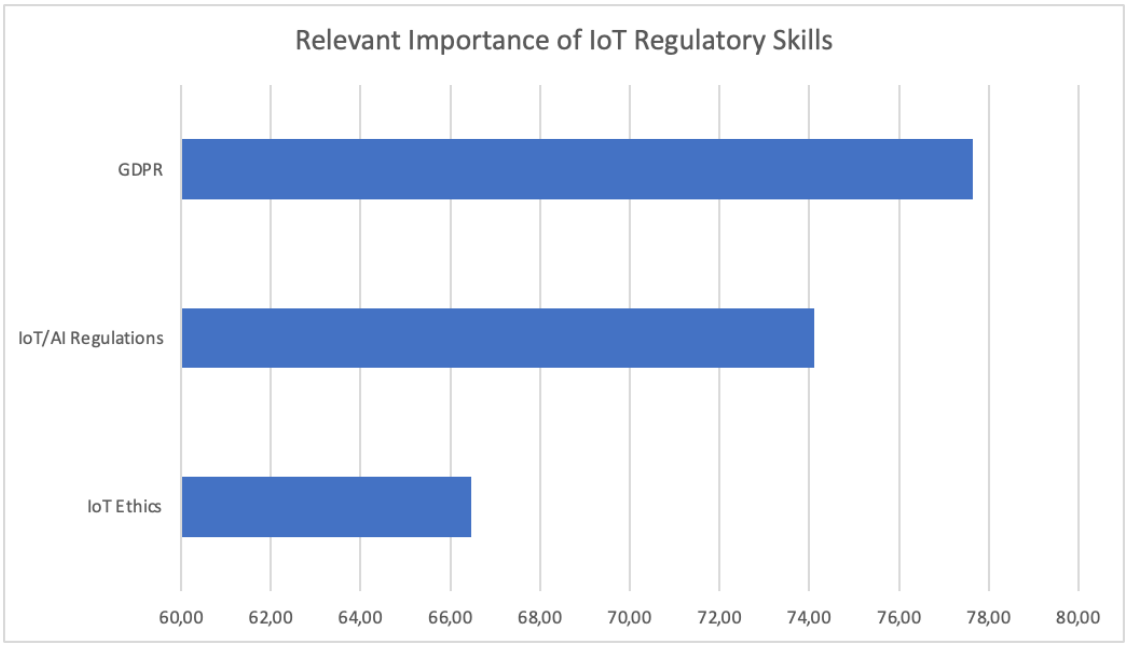

Figure 15: Relevant Importance of Legal and Regulatory Skills

4.2.3 IoT End-User and Operator 4.0 Sub-survey

The following figures illustrate the survey outcomes regarding the importance of end-user skills. Figure 16 presents industrial automation skills that are usually important for the development and deployment of industrial IoT applications. Digital twins' skills for IIoT applications were perceived as very important for IoT deployments. Skills related to more specific industrial applications have a lower rank due to their more limited generality and applicability. This is also the reason why simulation skills were ranked in the second position of the skills importance.

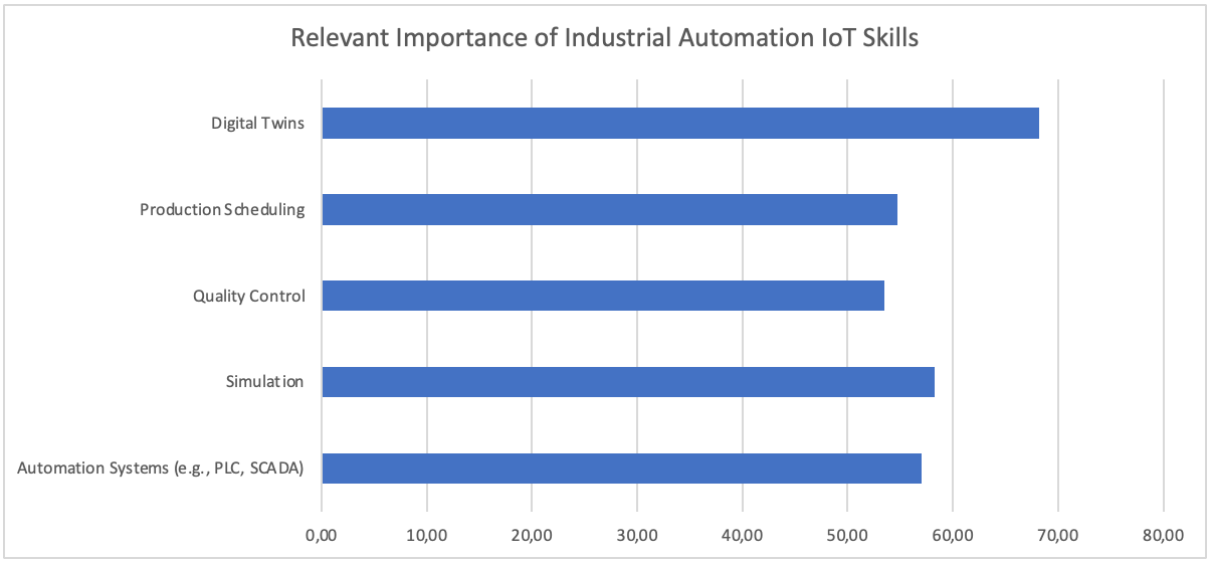

Figure 16: Relevant Importance of Industrial Automation Skills

Figure 17 presents the respondents' perceived importance of asset management skills. The outcomes confirm that predictive maintenance and intelligent asset management are considered among the most prominent industrial IoT applications.

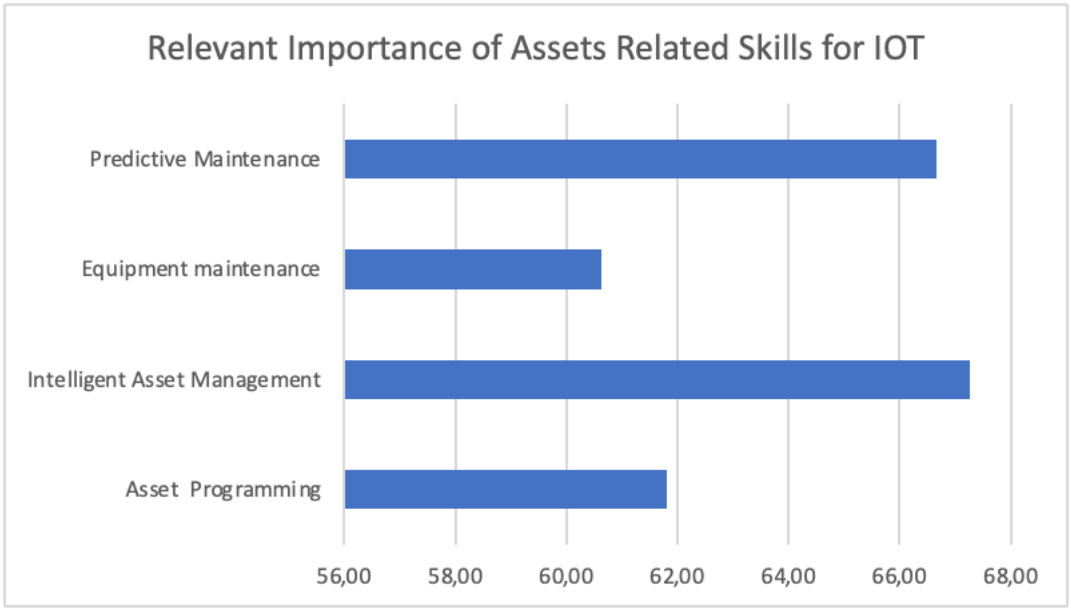

Figure 17: Relevant Importance of Asset Management Skills

The survey also targeted the ranking of various data and visualisation related skills for IoT applications (Figure 18). Big data visualisation is considered a very important skill with broad applicability. Human-centered technologies (e.g., ergonomic user interfaces) follow in the skills ranking.

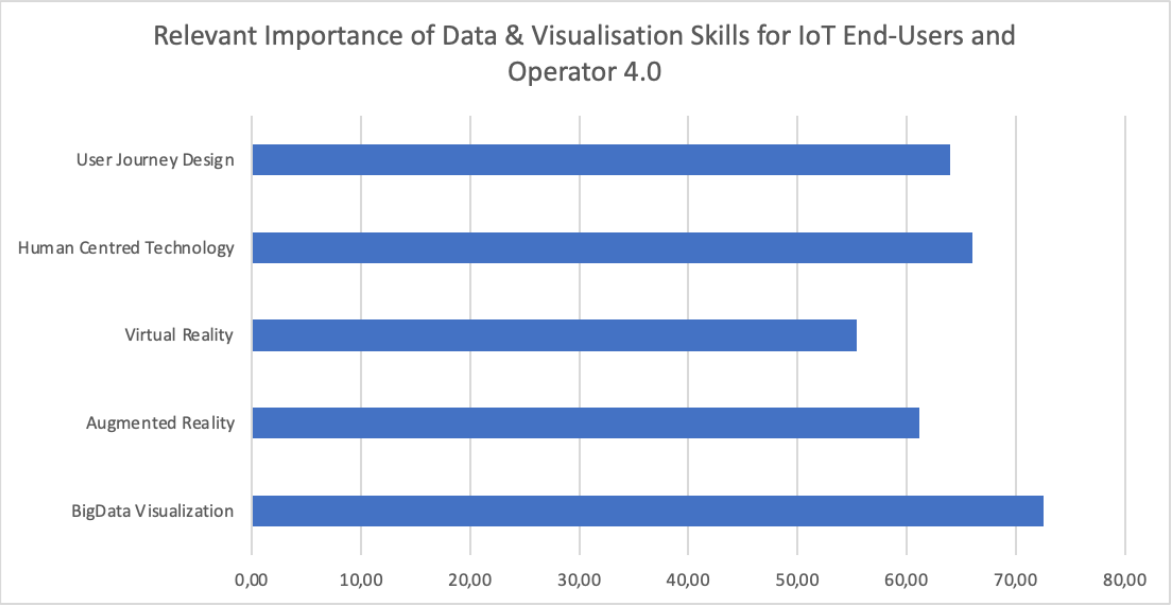

Figure 18: Relevant Importance of Data and Visualisation Skills

4.2.4 Social, Management, and Other Soft Skills Sub-survey

The following diagrams present the respondents' ranking of thinking, social and personal skills for IoT development. These sets of skills are considered as complementary to technical and management skills. In terms of thinking skills, collaboration was perceived as the most important skill followed by analytical thinking (Figure 19). Both skills play a significant role in the development and deployment of IoT applications.

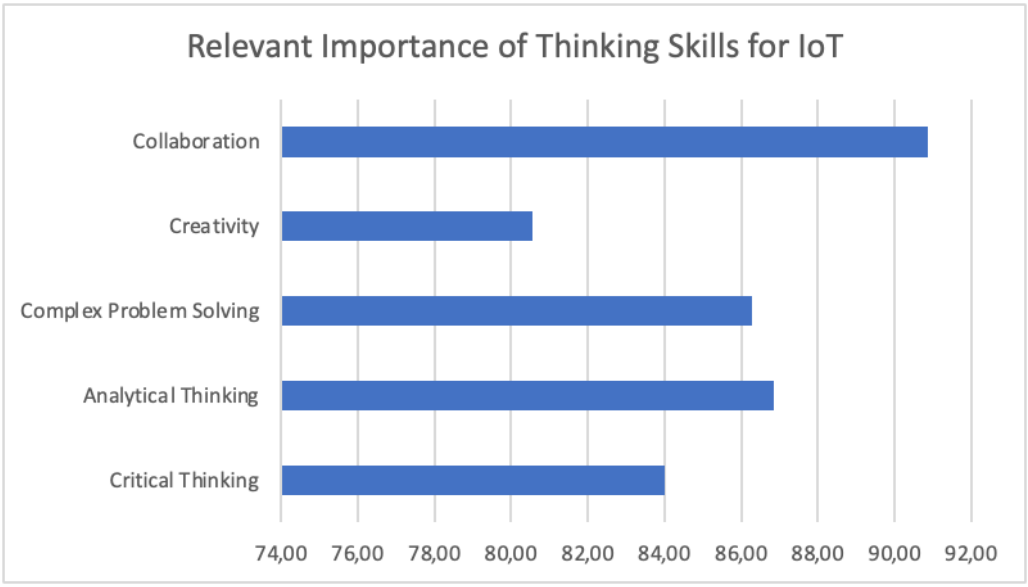

Figure 19: Relevant Importance of Thinking Skills

Figure 20 illustrates the relevant importance of various social skills for IoT. Teamwork is considered very important, which matches the findings of thinking skills where collaboration was prioritised.

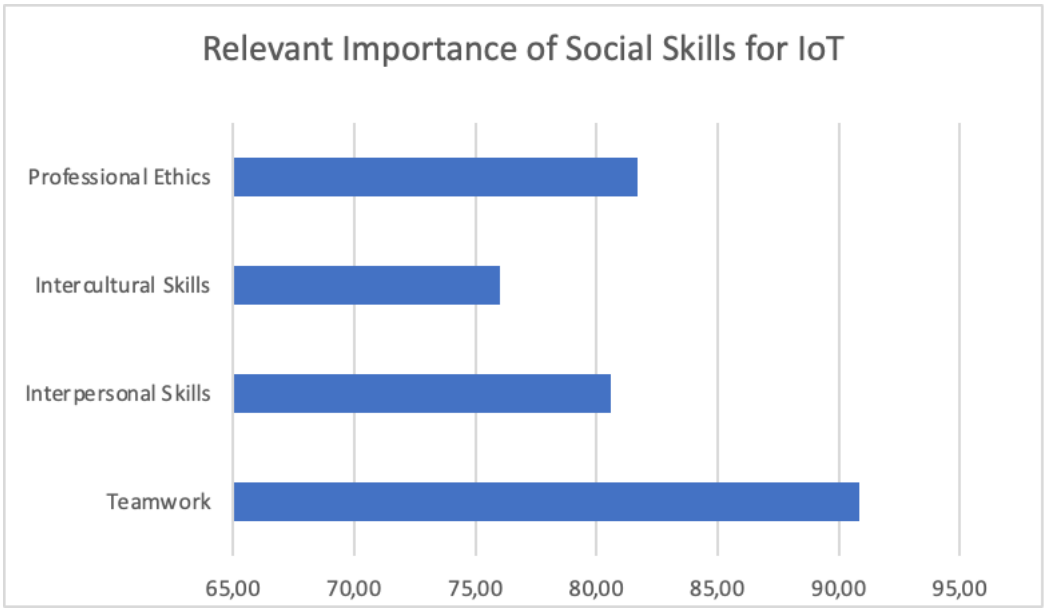

Figure 20: Relevant Importance of Social Skills

Lifelong learning was ranked as the most important personal skill for IoT developments and deployments. However, many other personal and soft skills (e.g., time management, emotional intelligence) were also considered of importance with quite similar scores (Figure 21).

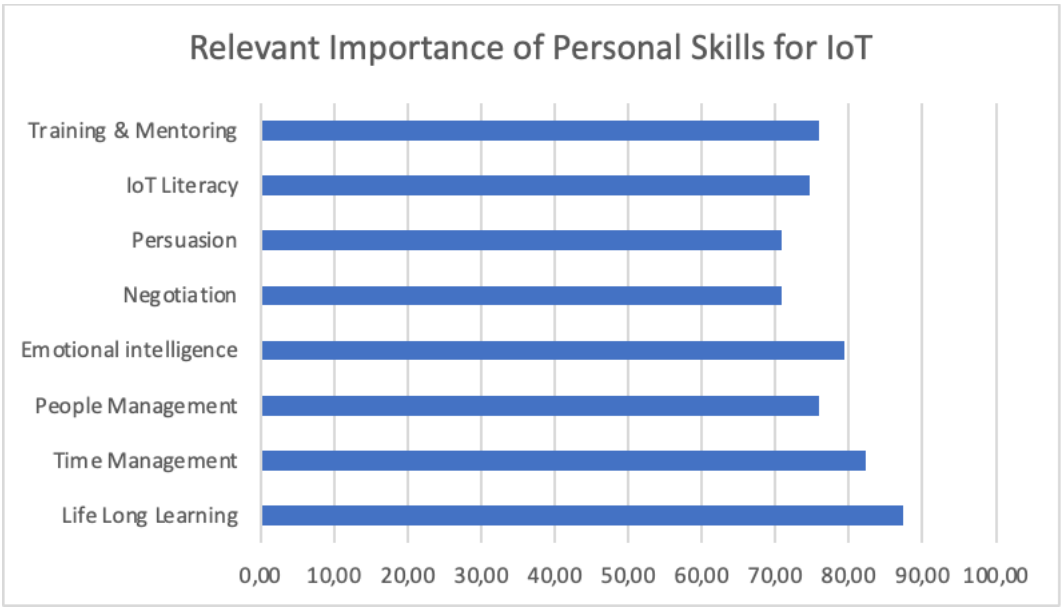

Figure 21: Relevant Importance of Personal Skills

4.3 Discussion of Survey Findings

The results of the survey indicate some of the most popular IoT skills according to the opinion of IoT professionals from different sectors. The popularity of the skills is closely linked to the market demand for these skills. Beyond the overall ranking of the individual skills, there are several useful findings that stem from the analysis of the responses of specific subgroups such as professionals in individual sectors. The main findings from the survey are as follows:

- **The most general and broadly applicable skills are the most popular as well**: The most popular skills were the ones that are broadly used in the scope of IoT systems and applications. This is because these skills enable professionals to engage in a wide range of IoT projects and activities.
- **Specialised skills are important for specific segments and groups of IoT professionals**: More specialised IoT skills are perceived as being very important for professionals within specific sectors. For instance, there are skills ranking very high within manufacturing (e.g., PLC) and skills that rank very high within sectors that handle sensitive data (e.g., healthcare).
- **Several soft Skills (e.g., lifelong learning) are very important**: Soft skills are a very important asset that complements the IoT technical and technological skills. Several soft skills (e.g., lifelong learning skills) ranked very high in the overall standings of the skills that were included in the survey. Specifically, there are many skills that were graded over 70% (e.g., time management skills, people management skills) in the scale of the survey's importance. Successful IoT professionals cannot afford to ignore soft skills.
- **The survey enables different approaches for clustering skills into skills profiles**: The skills survey can be used as a tool for clustering individual skills into skills profiles. One can set criteria on the ranked skills in order to associated them with skills profiles. A set of concrete and practical ways to do this is presented in the following section.

It is important to note that the results of the survey provide a snapshot of the IoT skills that are most popular and demanded at the given moment. As IoT integrates a broad set of technologies that advance at a rapid pace, the demand for specific IoT skills in the future cannot be known.

5 IOT LEARNING PATHS

5.1 Skills Profiles and Learning Path Construction Methodology

To excel in the development, deployment, and use of IoT systems and applications workers need more than IoT skills. For instance, IoT technical experts possess several of the previously presented skills from a single sub-category. As a prominent example, an IoT developer is likely to know more than one programming languages to excel in the programming of the IoT Stack. However, it is also common that IoT professionals possess technical skills from different sub-categories of technical skills, such as programming skills and skills relating to IoT protocols like MQTT and CoAP. Therefore, in most cases IoT professionals match entire skills profiles that comprise multiple skills from different technological areas as well as non-technical skills (e.g., the ever-important soft skills).

Clustering of multiple IoT skills into skills profiles is very important for training and skills development processes. The latter are usually driven by the need to develop professionals that possess groups of relevant skills that enable them to undertake roles such as IoT software developer, IoT data engineer, IoT software engineer, IoT systems architect, embedded systems developer and more. The EU-IoT skills framework can support the construction of skills profiles by facilitating interested stakeholders in selecting the skills to be clustered from a rich set of well-structured IoT skills. Using the framework stakeholders can easily identify available skills and how they relate to each other. Hence, they can structure relevant skills profiles that meet the needs of their organisations. There is a variety of different skills profiles such as hardware designers, embedded firmware developments, IoT networking experts, IoT solution integrator, IoT applications front end developers, IoT data scientists, IoT automation engineers and many more.

A skills profile can drive the specification of learning pathways (i.e., collections of courses and other didactic activities) that lead to the acquisition of the skills of a profile. These learning pathways can form the basis of entire training programs at academic or professional levels. The simplest form of a learning pathway specifications involves the structuring of a set of courses within a training programme.

EU-IoT provides three powerful tools that facilitate the construction of skills profiles and learning paths:

- **The EU-IoT skills framework**, which facilitates the construction of coherent skills profiles that comprise well-structured and complementary collections of courses.
- **The EU-IoT survey,** which can drive the specification of skills profiles subject to criteria like the overall popularity of certain skills, their relevance to specific industries (e.g.., manufacturing), as well as their complementarity. For instance, the most popular IoT analytics related technical skills can be used to form an IoT data scientist skills profile. As another example, a collection of popular methodologies (e.g., DevOps), tools (e.g., NodeRed), programming languages (e.g., Python) and devices (e.g., sensors, WSN) related skills can serve as basis for the specification of an IoT developer profile.
- **The EU-IoT training catalogue,** which provides a pool of training resources that can be used to specify training programmes that lead to the key skills of a given skills profile. Specifically, with a skills profile at hand, interested stakeholders can consult the IoT training resources catalogue to identify a concrete set of available courses that can be structured in a learning pathway for the given skills profile.

5.2 Sample IoT Learning Paths

The following tables provide six concrete examples of skills profiles, along with the skills they comprise. They also provide an indicative set of courses that can support the developments of the proper skills for each profile. The listed courses can be found in the Udemy training ecosystem and the EU-IoT training resources catalogue. Specifically, each of the table presents the following information for each one of the six skills profiles:

- **Individual Skills of the Profile**: This is the list of skills that an IoT professional must possess to qualify for roles associated with the skills profile. The presented lists are indicative. In principle, it is possible to broaden the scope of a skills profile by including additional skills in the list. As already outlined, the development of skills profile could consider the results of our survey towards including both relevant and popular skills in the profile.
- **Courses of the Learning Path**: This field includes a list of courses that can help professionals learn the listed skills. The tables include courses from the EU-IoT training catalogue and the Udemy training ecosystem. These courses are considered mandatory for acquiring the skills that are mandated by the skills profile. There is a variety of equivalent or similar courses in the training catalogue and in other ecosystems (e.g., Coursera, EdX) that could help build similar learning paths. In principle, the development of a proper learning path can be challenging process that should seek for the optimal complementarity and compatibility of the selected courses.
- **Other Relevant Courses**: This field includes additional courses that could strengthen the learning path for the skills profile as hand. These courses could be considered as optional or "nice to have" for the target profile. Like in the case of mandatory courses, the tables include courses from the EU-IoT training catalogue and the Udemy training ecosystem. However, there is a variety of equivalent or similar courses in the training catalogue and in other ecosystems (e.g., Coursera, edX) that could help to provide alternative collection of optional courses in order to strengthen the learning path.

IoT Skills Profile: IoT Application Developer	
Individual Skills of the Profile	
Python, JavaScript, IoT & Cloud Computing, DevOps, Docker, Kubernetes, Sensors, WSN, Arduino, MQTT	
Courses of the Learning Path	
1.	Practical IoT Concepts-Devices, IoT Protocols & Servers DevOps
2.	Introduction to IoT Programming with JavaScript
3.	Exploring AWS IoT
4.	Project - 2022: CI/CD with Jenkins Ansible Kubernetes
5.	Arduino For Beginners - 2022 Complete Course
Other Relevant Courses	
1.	Collaboration and Emotional Intelligence
2.	I.T. Project Management for Beginners: A Step-by-Step Guide

Table 2: Skills and Learning Path for the "IoT Application Developer" Skills Profile

IoT Skills Profile: IoT Network Engineer
Individual Skills of the Profile
Sensors & IoT Devices, LPWAN, 4G/5G/6G, WiFi, Bluetooth, MQTT
Courses of the Learning Path
1. Internet Of Things (IoT) - Demystified using 3 IOT devices **2.** 5G Masterclass: Architecture, NR RAN, Core and Call flows **3.** The Ultimate WLAN and WiFi Training Course **4.** The Complete Bluetooth / IoT Design Course for iOS
Other Relevant Courses
1. Collaboration and Emotional Intelligence **2.** I.T. Project Management for Beginners: A Step-by-Step Guide

Table 3: Skills and Learning Path for the "IoT Networking Engineer" Skills Profile

IoT Skills Profile: IoT Data Analytics Expert
Individual Skills of the Profile
Data Science, Machine Learning, TinyML, Sensors, WSN
Courses of the Learning Path
1. Master Machine Learning and Data Science with Python **2.** Intro to Embedded Machine Learning **3.** Sensors/Actuators/Data Visualization with Microcontrollers - IoT Dashboard with Arduino
Other Relevant Courses
1. Statistics for Data Science and Business Analysis **2.** Collaboration and Emotional Intelligence

Table 4: Skills and Learning Path for the "IoT Data Analytics Expert" Skills Profile

IoT Skills Profile: Embedded Systems Engineer
Individual Skills of the Profile
Embedded Systems, FPGA, Printed Circuit Board (PCB) Design, Sensors, Actuators, WSN
Courses of the Learning Path
1. Mastering Microcontroller and Embedded Driver Development **2.** Learn the Fundamentals of VHDL and FPGA Development **3.** Sensors/Actuators/Data Visualization with Microcontrollers - IoT Dashboard with Arduino **4.** Crash Course Electronics and PCB Design
Other Relevant Courses
1. Arduino: Electronics circuit, PCB Design & IOT Programming **2.** Collaboration and Emotional Intelligence

Table 5: Skills and Learning Path for the "Embedded Systems Engineer" Skills Profile

IoT Skills Profile: IoT Project Manager
Individual Skills of the Profile
Project Management, Sensors, WSN, DevOps, Agile Development
Courses of the Learning Path
1. I.T. Project Management for Beginners: A Step-by-Step Guide **2.** Agile PM 301 - Mastering Agile Project Management **3.** Project - 2022: CI/CD with Jenkins Ansible Kubernetes **4.** Sensors/Actuators/Data Visualization with Microcontrollers - IoT Dashboard with Arduino
Other Relevant Courses
1. Presentation Skills: Master Confident Presentations **2.** Management Skills - Team Leadership Skills Masterclass 2022 **3.** Collaboration and Emotional Intelligence

Table 6: Skills and Learning Path for the "IoT Project Manager" Skills Profile

IoT Skills Profile: IoT Product Manager
Individual Skills of the Profile
Product Management, Sensors, WSN, Cyber-Physical Systems
Courses of the Learning Path
1. Agile PM 301 - Mastering Agile Project Management **2.** Great Product Manager: Product Management by a Big Tech's PM **3.** Complete Guide to Build IOT Things from Scratch to Market **4.** Sensors/Actuators/Data Visualization with Microcontrollers - IoT Dashboard with Arduino
Other Relevant Courses
1. Presentation Skills: Master Confident Presentations **2.** Management Skills - Team Leadership Skills Masterclass 2022 **3.** Advanced Product Management: Vision, Strategy & Metrics

Table 7: Skills and Learning Path for the "IoT Product Manager" Skills Profile

Overall, the tables provide a set of representative examples that aim at illustrating the process of specifying learning paths based on available catalogues of training resources. There is however much room for interested stakeholders to fine-tune the learning paths development process by scrutinising the vast amount of training resources that are already available towards identifying their optimal complementarity and selecting the resources that are most appropriate for training an IoT professional in the key skills of a given profile.

6 CONCLUSION

Nowadays, there is a proclaimed gap in skills for automation and the future of work. Closing this skills gap is very important for adopting and leveraging cutting edge technologies of the fourth industrial revolutions in many economic sectors. IoT skills are among the most important elements of the skills puzzle, as IoT technologies have a broad scope and are widely used in sectors like manufacturing, energy, healthcare, transport, retail, agriculture, and supply chain management. State of the art skills surveys identify some of the skills that are high in demand in the market. Nevertheless, they usually take a broad view that address many different digital technologies rather than focusing on the IoT skills and the IoT market. Motivated by this gap, this whitepaper has:

- Summarised the findings of various skills surveys regarding the shortage of IoT skills.
- Introduced the EU-IoT skills framework i.e., a structured taxonomy of IoT skills, including technical, management, and user-related skills, as well as the ever-important soft skills for IoT professionals. The framework can be extended with additional IoT skills.
- Presented the findings of the EU-IoT skills survey, which has questioned over 100 IoT professionals about the relevant importance of the skills that are listed in the framework.
- Illustrated how the skill survey and the EU-IoT framework can drive the clustering of individual IoT skills into wider IoT skills profiles.
- Presented examples of learning paths for specific skills profiles leverage courses and training resources of the EU-IoT training catalogue.

Overall, the EU-IoT project has provided three tangible outcomes on IoT skills (i.e., the skills framework, the survey, and the training resources catalogue). These outcomes can provide great help to HR professionals and policy makers that plan, specify and execute skills development processes. At the same time, they are a valuable resource for IoT professionals that pursue self-paced learning, lifelong learning, and continuous career development.

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