

Article

Skills Requirements for the European Machine Tool Sector Emerging from Its Digitalization

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Abstract: The machine tool industry, which is the starting point of all the metal producing activities, is presently undergoing rapid and continuous changes as a result of the fourth industrial revolution Industry 4.0. Manufacturing models are profoundly transforming with emerging digitalization. Smart technologies like artificial intelligence (AI), big data, the Internet of Things (IoT), digital twin, allow the machine tool companies to optimize processes, increase efficiency and reduce waste through a new phase of automation. These technologies, as well, enable the machine tool producers to reach the aim of creating products with improved performance, extended life, high reliability that are eco-efficient. Therefore, Industry 4.0 could be perceived as an invaluable opportunity for the machine tool sector, only if the sector has a competent workforce capable of handling the implementation of new business models and technological developments. The main condition to create this highly qualified workforce is reskilling and upskilling of the current workforce. Once we define the expected evolution of skills requirements, we can clarify the skills mismatch between the workers and job profiles. Only then, we can reduce them by delivering well-developed trainings. For this purpose, this article identifies the current and foreseen skills requirements demanded by the machine tool industry workforce. To this end, we generated an integrated database for the sector with the present and prospective skills needs of the metal processing sector professionals. The presented sectoral database is a fundamental structure that will make the sector acquire targeted industrial reforms. It can also be an essential instrument for machine tool companies, policymakers, academics and education or training centers to build well-designed and effective training programs to enhance the skills of the labor force.

Keywords: Industry 4.0; skills; workforce; machining; machine tool sector; metal sub-sector; digitalization

1. Introduction

The “machine tool sector” is one of the significant sub-sectors of the metal industry managing and manufacturing sells and serving machine tool equipment and supplies [1,2]. It is applied to all stages of processes, along with the design, development, technical assistance and provision of solutions to customers regarding machine tools. The machine tool industry and the manufacturing technologies connected with it are pillars of modern manufacturing: They are the incipience of almost every metal manufacturing activity [3].

According to the International Organization for Standardization (ISO), a “machine tool” is a mechanical utensil, set up and powered, and generally employed to manipulate workpieces by removing or adding material or deforming mechanically in a selective manner [3,4]. There exists a large variety of metalworking machine tools with different technologies such as lathes, sheet metal forming machines, milling machines, grinding machines, electrical discharge machining (EDM) machines, laser cutting and additive manufacturing machines. Therefore, machine tools are an excessively heterogeneous group of products due to their high level of customization and variety regarding the size and the material of the piece of work being machined, the level of automation, speed or performance [5]. Stainless steel, aluminum, copper and titanium are examples of the metals being tooled [3]. Additionally, machine tools allow the manufacturing of other machines (including themselves) and components for key industries such as automotive, aerospace, energy and medical technology [3].

In recent years, the machine tool sector has undergone profound and continuous changes as a result of the ongoing industrial revolution, Industry 4.0 or the digitalization of Industry. The word “Industry 4.0” is related to novel manufacturing processes that are partially or fully mechanized by technology and instruments that interact independently through activities in the value chain [6]. Consequently, it is mainly based on the computers’ intelligent systems, electrical machinery and modern information technologies (ITs). Digital transformation is a predominant factor of the ongoing industrial revolution leading to the revolution of the traditional industry through intelligent manufacturing [7,8]. As a result, rapidly increasing digitalization has changed the progress of most sectors, in addition to the machine tool sector. Manufacturing models are still evolving with the on-going advancements in intelligent technologies such as the new generation of sensors, advanced robotics, artificial intelligence (AI), the Internet of Things (IoT), machine learning, Internet of Services (IoS), Cyber-Physical-Systems (CPS), cloud computing, machine-to-machine (M2M) communication, etc. These essential technologies enable a new stage in automation and give as a result more creative and efficient processes, products and services. They can be applied equally to a recently-constructed plant or to existing plants, which leads to the transformation of traditional manufacturing companies into intelligent production systems called “smart factories” [9]. Smart Factories integrate production, communication, computing and control processes into automated, digitalized and context-aware manufacturing systems to gain in the optimization of business models [10,11].

The development and introduction of the aforementioned innovative technologies and smart factories allow the machine tool sector to generate higher quality products with extended life and enhanced performance through process optimization [12]. Since the machine tool producers, in particular, are also responsible for providing the costumers a wide range of services including maintenance, gathering and analyzing real-time data through IoT, sensors, machine learning, etc. technologies has a substantial advantage for them. Industry 4.0 presents an incalculable opportunity for the machine tool sector as it reshapes and improves not only all the production processes, business models but also the quality of their services and the way that the sector adds value [13]. At the same time, flexible, progressively interconnected and complex processes are transforming the organizational structure, job profiles and skills requirements of the machine tool companies and the training of their workforce [13].

Conclusively, the machine tool sector urgently needs to build a competent, multi-skilled labor force that is capable of handling all the aforementioned technological developments and the implementation of new business models. Creating this professional workforce is simply possible through reskilling and upskilling of the current workforce. Only workers with upgraded skills, knowledge and credentials will have enough capability to adapt to the digital transition, shift in production systems and newly adopted working systems and trends, and they will enable the industry to keep up with the emerging digitalization. Addressing the current skills requirements and anticipating the potential skills requirements of the machine tool industry is the initial step for the continuous upskilling and reskilling of its labor force. This research accomplishes this objective by carrying out a detailed analysis and generating a sectoral database. Once the forecasted evolution of skills requirements are

defined, a long-term plan-methodology should be established for the implementation of new skills and minimizing the skills gap between the industry and the current workforce. It should incorporate tools that besides providing solutions for recruiting new talents, but also present well-organized training and education programs to current workers, and redesign work processes [6].

Taking everything into account, the machine tool sector crucially needs a clear roadmap leading the sector to know the present and future requirements of skills. Thus, the industry has been lacking tools for the implementation of new skills and competences. In addition, there is a lack of guidelines for policymakers in the field of education, which enable relevant degrees, subject-matter syllabuses and continuing education programs to be compatible with the skills needs of the sector. Our work is developed to respond to these needs. In the second section of this article, we analyzed the digital technologies that have a direct impact on the machine tool industry and clarified the challenges emerging from the implementation of these technologies in the sector. In the third section, initially, we determined the latest skills trends affecting the machine tool industry carrying out detailed desktop research. Then, we suggested a general strategic plan for the sector to acquire the required future skills. Finally, we presented the main objective of our research: developing a sectorial skills database by identifying the current and future skills needs of the sector. For this purpose, we essentially reviewed the skills implementation strategies adopted by other sectors (e.g., automotive, steel, construction) and created a methodology plan—adapted from a wide range of European sectoral and inter-sectoral projects and articles—for the machine tool industry to know the needs regarding future skills. Then, for the development of the database, we identified the present and near-future fundamental skills and competencies required for the occupations (engineers, operators and managers) in the machine tool sector. We utilized ESCO's database (database of European Skills, Competences, Credentials and Occupations) as the main data source for defining not only the current professional profiles in the machine tool sector but also the skills required for each profile. After, we built the automated database incorporating the selected profiles and current skills demanded by these profiles in an excel format applying Visual Basic for Applications (VBA). During the future skills development process, we evaluated the whole set of the job profiles in the database individually, and choose the profiles that would be altered due to the digitalization of the industry. While gathering data about the future competencies, we also used distinguished European references: a range of strategic sectoral and cross-sectoral European projects and frameworks. Once we identified the additional skills required for each profession, we incorporated them into our database to finalize the update process. Finally, we created a database of present and future skills required for each sectorial profile. In the last section of this paper, we discussed the main conclusions of our research, making suggestions to researchers, policy-makers, companies and training centers.

We aimed for the sectorial database to be used as a fundamental tool by the machine tool industry through all the future industrial changes. We believe that it will fulfill this aim. The target end-users of the established database are, therefore, machine tool sector companies, universities and education centers in charge of the development of training programs to meet the above-mentioned skills needs. We think that this research will be used by machine tool companies, academia and training centers as an essential framework guiding them to create the desired multi-skilled workforce.

2. Digitalisation of Machine Tool Industry

Even though the term "Industry 4.0" is relatively new, technological developments applied to machine tools first appeared almost 40 years ago and were increasing over time. Nevertheless, the launch and progress of the last industrial revolution strategy in recent years led to the exponential growth of the inventions related to the sector [14]. Therefore, the machine tool sector could benefit from Industry 4.0, which reshapes the industry and adjusts the whole production division [15]. According to the European Association of the Machine Tool Industries (CECIMO), continuous innovation and integration of the new technologies enable the European Machine tool industry to create products with a longer life cycle, provide upgraded completion and integrated solutions to customers, and they are

more reliable, safer to operate and eco-efficient [3]. New generation machine tools (Machine Tool 4.0) feature an extensive implementation of CPS, IoT, sensors, computing technologies and incorporate network connectivity, flexibility, foreseeability of intelligence, and real-time response loops [16,17]. Hence, digital technologies alter machine tools and convert them into intelligent assets, which are capable of collecting and exchanging real-time data about their condition and performance as well as their environment, thus providing transparency in the production process. Integration of these smart technologies in the sector serves one main function in particular: enhanced productivity. They allow the manufacturers to optimize processes, improve product quality, and reduce waste and production time through real-time problem solving and advanced process control [5]. As a result, their application enables machine tool manufacturers not only to maximize the equipment efficiency and to lower the production costs but also to offer novel services as predictive maintenance [5]. Predictive maintenance is an entirely new opportunity provided by Industry 4.0. It increases product reliability and availability and extends the lifetime of products [18]. Real-time data covering the state of the machine tool components and the period the tool operated are collected through sensors technology and IoT [19]. After the data collection, Big Data and Machine Learning solutions would enable building predictive models and algorithms capable of identifying potential failures and reducing downtimes through the early detection of possible problems prior to asset failure [18,20–23]. This predictive maintenance results in running continuously in machines and equipment are more efficient and prevent downtime [20,21]. The smart technologies, moreover, could be used to identify when machines are being used improperly and prevent human errors, evading inactivity and workplace injuries [20]. Industry 4.0 related technologies will also transform completely the quality assurance (QA) process by establishing real-time QA through an automated virtual metrology (AVM) system [20,24]. These systems consist of gathering data concerning conditions, quality, and state of the products, and combining them with information related to the machines and processes, and using a real-time element to QA inspections. This facilitates to carry manufacturing operations during a major QA inspection, with insignificant interruptions and immediate feedback [20,21]. Moreover, industrial cybersecurity has lately turned into a global concern and data safety has become a first-place priority globally. IoT has proved to be a solution to this issue since it enables the commodity to be detected and ensures traceability from cultivation to the supplied string [15,19]. In addition, the emerging digitalization trend makes an immense contribution to sustainable and resource-saving manufacturing [5,25]. Since machine tools are the starting point of almost every manufacturing activity, it has a tremendous impact on other sectors enabling them to have more sustainable manufacturing processes [5]. It is well-known that machine devices and their hardware consume a lot of energy. Digital technologies are making the consumption of resources easier to measure: The IoT sensors and platforms are used to collect data on energy use and inform operations while using smart meters and other smart tools are utilized to control the flow of energy efficiently [19–21]. Thanks to these technologies, better control of the manufacturing process and traceability make it possible to optimize business operations, maximize energy efficiency, reduce waste and manage resources more efficiently [5]. “Digital twin” is another 4.0 technology that has a lot of promise for the machine tool sector. It provides intelligent, machine-level decision-making at a factory level. As an example, digital twins of processes can offer options to fix the machine tool to engineers and assist technicians to pick the best time for repairs considering the entire downstream process [5]. Incorporating the aforementioned 4.0 technologies would guide a speedier industrial transformation process in the machine tool industry. It would shift the market abruptly, making it easier to manufacture better quality machine tools in a shorter period and at a lower cost. As well, hardware-oriented skills such as additive manufacturing represent a tremendous challenge that will influence the sector due to a higher possibility of shorter series, retro-fittings and repairs based on this relatively new technology [26]. Machine tools are barely mass-produced, and, in the majority of the cases, their initial designs are modified in order to meet customers’ specific requirements related to workpiece geometry or production completions. Accordingly, the machine tool producers are expected to provide a broad range of services for the customers particularly as regards maintenance, repair,

application engineering and on-site training [5]. Since the average European machine tool company is a Small or Medium-Sized Company (SME), it is challenging for the machine tool producers to answer to high expectations. If these companies make good use of emerging digitalization and integrate the 4.0 technologies into their production plants at full capacity, they will be able to respond to their customers' demands effectively and extremely improve their quality of services.

At the same time, implementing Industry 4.0 in the machine tool sector (as in other sectors) has some inherent risks and disadvantages including (a) the negative impact of data sharing in a competitive environment, (b) the need of completing the digital transformation on the whole supply chain for the success, (c) the need of handling employees and trade unions apprehension for the automation of low degree operations (d) the need of highly skilled (and/or continuously trained) labor, (e) the socio-technical implications of Industry 4.0 (e.g., related to the aforementioned polarization of jobs, the shift in favor of capital away from labor, etc.), (f) cyber-security issues in operations and plants and g) the significant initial cost and time for its implementation [27].

On the other hand, most European Machine Tool producers being SMEs [5] has certain drawbacks because SMEs are faced with considerably more challenges in undergoing digital transformation processes than large corporations. They can struggle to keep up with digitalization particularly in terms of both the implementation of new technologies and the training of the workforce. In the long-term, if they fail to handle these innovative technologies, they will be pushed out of the market. Therefore, they should try to focus on innovation and look for support in order to keep their global competitiveness. A substantial amount of support can be provided to these companies through well-developed skills policies, well-targeted supporting measures at EU and national levels, and European frameworks for training and professional development in schools, universities, other higher education institutions and companies [13,28]. If SMEs get the necessary support and are encouraged enough to implement the required transformation and modification of content, methods and business models, the machine tool sector will reap considerable rewards in a not too far future.

3. Identifying the Current and Future Skills Requirements for the Machine Tool Sector

In this section, we focused on identifying the skills needs (current and near-future) of the machine tool workforce. For this purpose, we firstly analyzed the latest skills trends affecting the machine tool industry carrying out detailed desktop research. Then, we suggested a long-term skills strategy for the sector to meet future skills requirements. Ultimately, we presented the methodology and results of our research: development of the automated skills database for the machine tool sector.

3.1. General Skills Trends for the Machine Tool Sector

The key requirement to identify the anticipated evolution of skills needs is to have a general portray of the future machine tool sector. It can only be achieved by analyzing the industrial changes brought by Industry 4.0. Firstly, because of the real-time data generated by smart and automated production systems, employees will be capable of making more informed decisions and dealing with complex situations. Most workers will be managing their daily operations alongside robots and machines [21]. Many jobs performed physically by using machine tools will be carried out by operating them through computers, monitoring data, and providing oversight to automated activities. Thanks to advanced robotics technology, collaborative robotic systems will take on simple and monotonous tasks, whereas operators will execute tasks that need higher skills and make crucial decisions [29]. Automation will also result in improved safety allowing workers to stay at a safe distance from the machines [20]. The integration of artificial intelligence will reinforce team-orientation, and conventional top-down hierarchical organizations will lose influence. Teamwork between co-workers and automated systems will gain importance [30]. In general, work profiles would be required to perform a more complex and wider range of tasks in different departments. It is also predicted that staff would have broader experience and skills in a variety of subjects [29].

In general, the integration of digital innovations demands the development of new technological and transversal skills among the machine tool workforce. This will require retraining and reskilling of the workforce. The most observed effect of these technological innovations is the increasingly growing demand for technological skills [29,31]. These incorporate basic digital skills, along with advanced technological skills, such as computing, data analysis and evaluation [13,31]. As a result of this demand, data security together with data safety will become more relevant [24]. Social and emotional skills will also be highly demanded due to the implementation of advanced technologies [29,31]. And the workforce will be responsible for more important tasks due to growing automation. These tasks will require numeracy, advanced literacy, information and communications technology (ICT) as well as several soft skills such as problem-solving skills, initiative-taking, and teamwork skills [32,33]. Cognitive skills needs will be altered from a basic level to a higher one since the automation of computers will reduce the number of tasks requiring basic cognitive skills (such as auditory and visual processing) [31]. Higher cognitive skills, for example, creativity, thinking strategically, teamwork, lifelong learning, decision-making, problem-solving, and so on, will become crucial [25,31]. In addition, skills like problem management, processing and abstracting complex information (in order to achieve a simpler representation of the larger picture), critical thinking, cross-functional process know-how, interdisciplinary thinking and acting as well as communication skills, and customer relationship management would be expected from the near future workforce [13,29,32]. Depending on the variety of automated tasks, the needed manual and physical skills would be updated. Regardless of the reduced demand, they will continue being the largest group of workforce skills [31]. Other significant classes of skills are green skills; They are considered essential to sustain the aspiring power of the European manufacturing industry for the increasing emphasis on sustainability [34].

3.2. Long-Term Skills Strategy

This chapter presents a general strategic plan for the machine tool sector to fulfill future skills requirements. The long-term strategy guides the sector by identifying the skills gaps between what the industry expects and what the workforce delivers as well as bridging these gaps and implementing the new skills gaps. The activities that these long-term skills approach covers should encourage the workforce to be proactive in integrating new technologies that optimize production and increase productivity. In order to minimize the time needed for the complete digitalization of the sector, the activities must provide supervision for implementing the skills and developing the tools for the implementation through training programs [25,35–40]. To complete an effective digital transformation in the sector, this proactive skills strategy should include the following steps: The first step is to evaluate the actual status of digitalization of the sector [25] (the machine tool industry, in this case) and to examine the key trends related to foreseen technological developments [37]. Once the most significant technological innovations and relevant skills needs are identified, a proper future scenario can be established. Economic innovations connected with digital transformations should also be taken into consideration in this scenario [25]. The industrial processes and the job profiles impacted by the digital transition will be also analyzed. The second step involves identifying the professional profiles and the skills that the future will demand and defining the skills gaps generated by current and expected technological developments [25,37]. The most critical part of this process is to define the skills needs of the industry in a pro-active and constructive manner, taking skills shortages into consideration [33]. An automated database with the required skills and competencies of the job profiles of the sector will be created. This database will provide international recognition and a common basis for the skills and professions required in the machine tool sector. In the following phase, the instruction and curricula needs will be established taking skills gaps into account. After, training programs for the identified skills needs and professional profiles will be created [37]. In addition, companies, formal education and training centers should develop new methods for delivering the educational content more efficiently and rapidly. Training contents and systems should be updated constantly in order to achieve higher quality programs [25]. Since workplace training for Industry 4.0 is the key to the

success of industrial enterprises [13], company training contents will be the main focus of this step. Training programs should also include talent management and recruiting methods in their contents [25]. On the other hand, in order to carry out the relevant adjustments in the education and training systems, the constantly changing list of skills requirements must be regularly updated [13]. By following this roadmap, machine tool companies and training centers can ensure a good matching between the skills demanded by the sector and skills delivered by the training programs and consequently, they will develop new common standards for the skills [25,40]. And then, the final step will be to find innovative approaches to draw more qualified people to the machine tool sector, to boost prospects for a more diverse pool of talent and to address recruitment obstacles [25,37,38].

Our work includes the first two steps of the plan.

3.3. Development of the Sectorial Database

The main objective of this research was to create a database of skills requirements (present and near-future) for the machine tool sector professional profiles. This section presents the development of the methodology and results of the research.

3.3.1. Materials and Methods

As in the previous studies of our research team [41–43], the methodology developed in this work combines detailed desk research of publications, cross-sectorial European frameworks and projects with the compilations of subject matter experts' opinions about the skills needs of the machine tool sector.

During the creation of the database presented here, we adopted two main references: the ESCO database (produced by the homonymous ESCO association—European Multilingual Classification of Skills, Competences, Qualifications and Occupations—developed by the European Commission); and ESSA (Industry-driven sustainable European Steel Skills Agenda and Strategy)—an EU project in which we directly took part and which aims to develop a Blueprint for “New Skills Agenda” [25]. Also, we exploited the desktop research that we performed during the development of Section 2 (identifying the digital technologies used by the machine tool sector) and 3.1 (the future skills trends for the machine tool sector). We, in addition, used the European ICT System of Professional Role Profiles (managed by CEPIS, the Council of European Professional Informatics Societies, and CEN, the European Committee for Standardization) as an important source. Moreover, we benefited from a range of strategic sectoral and inter-sectoral European or national initiatives, in some of which we participated: Procedures for Quality Apprenticeships in Educational Organizations (APPRENTICESHIPQ) [38], Digitalization of Small and Medium Enterprises, SMEs (SMeART) [39], SPIRE-SAIS (multi-sectorial, for energy efficiency and industrial symbiosis) [40], Machine tool alliance for skills (METALS) [44], CECIMO Circular Economy Report [5] and ACETECH Industrie 4.0 Skills Development Study [13]. Therefore, it is essential to provide definitions of the aforementioned references in favor of a clear understanding of the research. ESCO can be referred to as a dictionary of qualifications, skills and professional occupations related to the labor market, training and education [45], where the aforementioned terms are all defined in detail and classified accordingly. The data present in the ESCO database is grounded in the original framework: “International Standard Classification of Occupations” (ISCO-08) released by the International Labor Organization (ILO). Therefore, ESCO is directly linked with ISCO, the International Standard Classification of Occupations, which offers a wide categorization of occupational groups supervised by ILO. Additionally, CEPIS is a non-profit-making institution that aims to promote the development of renowned standards among IT practitioners acknowledging the effect of information technology on jobs, society and industry [46]. Moreover, the CEN (European Committee for Standardization) is an organization that connects the National Standardization Entities of 34 European countries promoting standardization activities in a wide variety of sectors and fields [47]. These two organizations supported the development of the European ICT Professional Role Profiles Framework aiming at contributing to a common European reference way of communication for the growth, planning and management of the professional needs regarding ICT from a longstanding

perspective and to the complete blooming of the ICT profession [48]. Finally, ACETECH is the German National Academy of Science and Engineering which was funded by the Federal German Government in order to provide independent, evidence-based advice on strategic engineering and technology policy issues to policymakers and the public [49]. The study of ACETECH which we used in this work, Industrie 4.0 Skills Development Study, was developed to identify the skills required by SMEs to increase the efficiency of industrial processes [13].

As indicated, we used VBA as the programming language in Microsoft Excel for the generation of the automated database for job profiles. It is also worth mentioning that an Application Programming Interface was developed in order to automate the updating of the developed database. It was needed to keep up with the ESCO's updating processes since ESCO updates its profile database regularly.

3.3.2. Results and Discussion

The goal of our research methodology has been to generate an automated database of skills requirements (present and near-future) for the machine tool sector professional profiles.

During the selection of the sector related job profiles and detection of their current skills requirements, we used ESCO's research as our main data source. We initially selected all the machine tool sector-related occupations in the ESCO database. Once we extracted them from the database, we incorporated them into a word excel spreadsheet. Then, we performed an automation process using VBA in the excel file. As a result, we generated the first version of the automated database which included only the current skills requirements for the selected occupations.

The next step was to identify future skills requirements and integrate them into the database.

ESCO provides us a very useful database that serves as a reliable, systematic and effective reference to obtain information about professional occupations and skills relevant to the EU labor market. However, it does not incorporate satisfactory information about the new skills needs emerging with technological innovations digitalization of each sector. Additionally, it does not include transversal skills. ESCO's content needs to be updated about future skills demands as a consequence of the natural evolution of occupations. As a result, we utilized other references dealing with the future skills requirements of the machine tool sector.

During the identification process of future skills and competencies, we performed desk research about the digital technologies used in the machine tool industry (Section 2) and general future skills trends for the sector (Section 3.1). It provided us a general idea about the additional skills that are demanded from the workforce to accomplish the full sectorial digital transformation and to obtain a competitive and sustainable machine tool sector.

Then, we applied the general aspects of the methodology that we had created in ESSA on the machine tool sector. Thus, we used the ESSA project as our main reference for defining future skills. Subsequently, we selected the most relevant skills from the European ICT Professional Role Profiles framework (ICT related skills), SPIRE-SAIS project (green skills), METALS project (technical, green and transversal skills), and the aforementioned researches performed by CECIMO association (technical and green skills) and ACETECH (transversal skills) and identified the specific and general skills that will be needed by the machine tool sector workforce in the near future. Combining this process with the detailed research carried out in Sections 2 and 3.1, and compilations of subject matter experts' opinions, we generated a final list for the future skills needs of the machine tool sector. Tables 1–3 demonstrate the final future skills lists. We also classified these new skills as technical skills, green skills and transversal skills to be practical.

Table 1. Final list of the identified future technical skills for the machine tool workforce.

Technical Future Skills for the Machine Tool Industry
IoT
Big Data
Artificial Intelligence (AI)
Sensors Technology
Augmented Reality
Machine Learning
Business Intelligence (BI)
Cloud Computing
Collaborative/Autonomous Robotics
Agile human-machine interfaces (HM)
Cyber-physical systems (CBS)
Augmented Reality (AR)
Digital twin
Additive Manufacturing
Post-processing
Laser technology
3D printing
Reverse engineering
CURA 3D software
ERP and MES systems
Communication among components, equipment (M2M), and environment
Online inspection and monitoring systems
Equipment and process monitoring & its implementation
Automated virtual metrology (AVM) system
Traceability
Blockchain
Predictive and Proactive maintenance
Computerized Maintenance Management
Process simulation and integration in manufacturing
Virtual systems for process simulation and for process control
Basic digital skills
Basic data input and processing
Advanced IT skills and programming
Advanced data analysis and modelization
Data management-safe storage,
Cybersecurity
Use of digital communication tools
E-commerce
Financial literacy
Knowledge and understanding of quality procedures related to digital transformation

After identifying the future skills, the next step was determining the job profiles that would undergo transformations due to the digitalization of the machine tool sector. For executing this task, we analyzed all the selected professional profiles individually. To this end, we firstly benefited from the aforementioned European projects in different sectors (steel, automotive, smart engineering, and so on) to observe the job profiles which needed to be updated due to technological developments. Then, we identified machine tool job profiles having equivalent tasks with those in other sectors (production manager, industrial manager, process engineer, project manager, etc.) which had been transformed by Industry 4.0. We took their future skills requirements and incorporated them into the database. In particular, the European ICT Professional Role Profiles Framework not only gave us the ICT-related occupations whose competencies have been altered by Industry 4.0 but also their future skills. For the rest of the machine tool occupations in the database, it was us who decided whether their skills needed an update due to digitalization or not. Whenever an update was deemed necessary for a professional profile, its future skills needs were added manually after a detailed study based on the opinions of experts on the subject matter. Before their integration into the database,

we also evaluated future skills for each professional profile one by one in order to divide them into two categories: essential and optional.

Table 2. Final list of the identified future transversal skills for the machine tool workforce.

Future Transversal Skills for the Machine Tool Industry
Advanced communication skills
Negotiation skills
Customer relationship management
Interpersonal skills and empathy
Leadership and managing others
Entrepreneurship and initiative taking
Risk management
Opportunity assessment
Adaptability and adapt to change
Continuous learning
Teaching and training others
Critical thinking and decision making
Cross-functional process know-how
Interdisciplinary thinking and acting
Personal experience
Ethical skills
Cultural empathy
Work autonomously
Active listening
Teamwork skills
Basic numeracy and communication
Advanced literacy
Quantitative and statistical skills
Complex information processing and interpretation
Process analysis
Appropriate linguistic skills
Creativity
Conflict resolution
Complex problem solving

Table 3. Final list of the identified future green skills for the machine tool workforce.

Future Green Skills for the Machine Tool Industry
Environmental awareness
Energy efficiency
Platforms for energy management of equipment and plants
Monitoring systems of energy consumption
Sustainable resource management
Waste reduction and waste management
Water conservation
Resource reuse/recycling
Knowledge and understanding of international and national standards and legislation
Product life cycle impact assessment
Circular economy
Climate change risk management

Eventually, we incorporated all the defined future skills and competencies into our database and concluded the update process. As a result, we finally achieved the automated skills database for the machine tool sector.

In addition, it is important to state that for the purpose of this work we assumed that all current skills present at the ESCO database will also be required in the future. If they become outdated in the future, they will be eliminated from both ESCO's and our database. However, it is not the case at

the time being. Furthermore, when we detected a future skill need in our research and it was already present in the ESCO database, we did not name it as a “future skill” anymore; only the new and additional skills needs that we identified were referred to as “future skills”.

Table 4 shows an example tab from the database created for the machine tool sector. In this particular case, the “industrial designer” professional profile is shown as an example. The hierarchic order of the occupational groups is presented at the first four rows of the table: The “industrial designer” job profile belongs to the “product and garment designers” group, which is part of the broader “architects, planners, surveyors and designers” occupation group, and so on. The database also includes a web link to the ESCO website where all the presented information about the job profile is available. Additionally, the table shows the alternative labels for the introduced job profile along with the ISCO profile number. This number is the international occupation code for the ISCO. Furthermore, the table details the (essential and optional) skills and knowledge needs of the “industrial designer” profile. The current skills needs which were extracted from the ESCO database are presented in black whereas the future skills which were introduced through our present research are in red. The complete version of Table 4 is present in the Supplementary Materials.

Table 4. An example job profile extracted from the generated machine tool sectorial database (shortened version).

Professionals
Science and engineering professionals
Architects, planners, surveyors and designers
Product and garment designers
Professional Job Profile: Industrial Designer
ESCO link: http://data.europa.eu/esco/occupation/ab7bccb2-6f81-4a3d-a0c0-fca5d47d2775
product design specialist//industrial designers//product designer//CAD design expert//industrial design expert//3D CAD design specialist//industrial design specialist//3D CAD design expert//ergonomic designer//packaging designer//CAD design specialist//ceramic products designer//product design expert//glass products designer//CAD designer//3D CAD designer//toy designer
Industrial designers work out ideas and develop them into designs and concepts for a wide variety of manufactured products. They integrate creativity, aesthetics, production feasibility, and market relevance in the design of new products.
ISCO number: 2163
Essential
Knowledge
Aesthetics copyright legislation design principles engineering principles engineering processes Ergonomics industrial design manufacturing processes Mathematics
Skill/Competence
conduct research on trends in design determine suitability of materials draft design specifications draw design sketches follow a brief liaise with engineers

Table 4. Cont.

meet deadlines perform market research present detailed design proposals
Optional
Knowledge
3D modeling CAD software CAM software cost management Hydraulics industrial engineering
Skill/Competence
adapt existing designs to changed circumstances adapt to new design materials analyze production processes for improvement apply 3D imaging techniques create a product's virtual model design prototypes determine production feasibility draw blueprints identify customer's needs monitor production developments prepare production prototypes use CAD software use CAE software
Future skills
Essential
advanced data analysis and modelization additive manufacturing quantitative and statistical skills basic digital skills energy efficiency product life cycle impact assessment circular economy Cybersecurity inspecting and monitoring skills teamwork skills use of digital communication tools critical thinking and decision making complex information processing and interpretation IoT technology CURA 3D software collaborative/autonomous robots big data cloud computing sensors technology machine learning Traceability
Optional
adaptability and continuous learning teaching and training the others interdisciplinary thinking and acting active listening process analysis

This can be considered a smart table thanks to the automation process of the database. Hence, in the excel spreadsheet of Table 4, when we change the “industrial designer” job profile to another profile, all of the information connected with the new profile is displayed automatically in the table, substituting the data about “industrial designer”. This ability allows the database to show the skills needs of any job profile immediately and makes it a very useful tool during the implementation of skills.

Table 5 provides a succinct view of the automated database that we generated: two professional profiles related to the machine tool sector, their description, ISCO numbers and their current skills needs. All the displayed data in this table is extracted from ESCO. On the other hand, our contribution to the database through this research is demonstrated in Table 6: future skills needs of the two selected profiles. These recently added skills are chosen from the list of technical, transversal and green skills presented in Tables 1–3. The full versions of Tables 5 and 6 (with all the machine tool job profiles) can be found in Supplementary Materials.

Table 5. A view of the automated database for the professional profiles related to the machine tool sector: profile description, weblink, alternative labels ISCO number and current competencies (in excel format).

ESCO Occupation	Industrial Tool Design Engineer	Tooling Engineer
Weblink to ESCO	http://data.europa.eu/esco/occupation/8bc48c43-d976-458a-9e3c-ee784572351d	http://data.europa.eu/esco/occupation/79fed799-ab3a-43d9-bd91-414c2c3b2f57
Alternative labels	industrial tool engineering specialist//industrial tool design quality control supervisor//industrial tool design developer//tool design engineer//industrial tool technology engineering specialist//industrial tool design producer//industrial tool production supervisor//industrial tool developer//industrial tool technology engineering adviser//industrial tool designer//industrial tool production designer//industrial tool production specialist engineer//industrial tool technology engineering expert//industrial tool development engineer//industrial tool technology engineering consultant//industrial tool test engineer//industrial tool engineering expert//industrial tool graphic designer//industrial tool engineer//industrial tool engineering consultant//industrial tool technology engineer//industrial tool engineering adviser	tooling technology engineering adviser//tooling engineering adviser//tooling technology engineering expert//tools engineer//tooling technology engineering consultant//press tooling engineer//tooling design engineer//tooling technology engineer//tooling engineering consultant//toolmaker//tooling engineering specialist//tooling development engineer//tooling technology engineering specialist//manufacturing tooling engineer//tooling engineering expert//toolmaker/tooling engineer
Description	Industrial tool design engineers design various industrial tools in accordance with customer needs, manufacturing requirements, and building specifications. They test the designs, look for solutions to any problems, and oversee production.	Tooling engineers design new tools for manufacturing equipment. They prepare tooling quotation requests. They estimate costs and delivery time, manage tooling construction follow-up and supervise the routine maintenance of tools. They also analyze data to determine the cause of major tooling difficulties and develop recommendations and action plans for solutions.
ISCO Number	2144	2144
	essential knowledge	essential knowledge
	CAD software design drawings industrial engineering industrial tools manufacturing processes mathematics mechanical engineering mechanics production processes	CAD software CAE software engineering principles engineering processes ICT software specifications industrial engineering manufacturing processes mathematics mechanics

Table 5. Cont.

ESCO Occupation	Industrial Tool Design Engineer	Tooling Engineer
	technical drawings	multimedia systems
	skill/competence	physics
	adjust engineering designs	production processes
	approve engineering design	quality and cycle time optimization
	create solutions to problems	reverse engineering
	design prototypes	technical drawings
	execute feasibility study	skill/competence
	identify customer's needs	adjust engineering designs
	inspect industrial equipment	approve engineering design
	perform scientific research	build a product's physical model
	provide technical documentation	create a product's virtual model
	read engineering drawings	determine production feasibility
	troubleshoot	estimate duration of work
	use CAD software	execute analytical mathematical calculations
	use specialized design software	perform scientific research
	use technical drawing software	provide cost-benefit analysis reports
	optional	read engineering drawings
	knowledge	use a computer
	3D modeling	use CAD software
	engineering principles	use computer-aided engineering systems
	engineering processes	use technical drawing software
	material mechanics	optional
	reverse engineering	knowledge

Table 5. Cont.

ESCO Occupation	Industrial Tool Design Engineer	Tooling Engineer
	skill/competence	3D modeling
	advise on safety improvements build a product's physical model	electromechanics material mechanics
	create a product's virtual model	skill/competence
	determine production capacity determine production feasibility estimate duration of work maintain industrial equipment manage supplies	advise customers on new equipment analyze production processes for improvement attend trade fairs communicate with customers design prototypes
	monitor production developments plan manufacturing processes provide advice to technicians provide cost-benefit analysis reports	determine production capacity ensure compliance with environmental legislation liaise with engineers manage health and safety standards
	use a computer use computer-aided engineering systems	manage supplies monitor production developments

Table 6. A view of the database for the professional profiles related to the machine tool sector: future competencies (in excel format).

Industrial Tool Design Engineer	Tooling Engineer
Essential Future Skills	Essential Future Skills
IoT big data collaborative/autonomous robotics artificial intelligence machine learning cloud computing digital twins agile human-machine interfaces (HM) cyber-physical systems (CBS) augmented reality (AR) Cura 3D software cybersecurity additive manufacturing automated virtual metrology (AVM) system traceability blockchain virtual systems for process simulation and for process control basic data input and processing advanced data analysis and modelization data management-safe storage, cybersecurity use of digital communication tools advanced communication skills interpersonal skills and empathy entrepreneurship and initiative-taking risk management critical thinking and decision making Interdisciplinary thinking and acting active listening teamwork skills advanced literacy quantitative and statistical skills complex information processing and interpretation complex problem solving environmental awareness energy efficiency product life cycle impact assessment circular economy	IoT big data collaborative/autonomous robotics artificial intelligence machine learning cloud computing agile human-machine interfaces (HM) cyber-physical systems (CBS) augmented reality (AR) process analysis additive manufacturing post-processing laser technology 3D printing ERP and MES systems communication among components, equipment (M2M), and environment online inspection and monitoring systems equipment and process monitoring & its implementation automated virtual metrology (AVM) system traceability predictive and proactive maintenance computerized maintenance management process simulation and integration in manufacturing virtual systems for process simulation and for process control basic data input and processing advanced data analysis and modelization data management-safe storage, use of digital communication tools advanced communication skills interpersonal skills and empathy entrepreneurship and initiative-taking risk management critical thinking and decision making Interdisciplinary thinking and acting active listening teamwork skills advanced literacy quantitative and statistical skills
Optional Future Skills	complex information processing and interpretation complex problem solving environmental awareness energy efficiency platforms for energy management of equipment and plants monitoring systems of energy consumption sustainable resource management waste reduction and waste management water conservation

Table 6. Cont.

Industrial Tool Design Engineer	Tooling Engineer
adaptability and adapt to change	resource reuse/recycling
cultural empathy	product life cycle impact assessment
work autonomously	circular economy
appropriate linguistic skills	Optional Future Skills
creativity	cybersecurity
conflict resolution	digital twins
knowledge and understanding of international and national standards and legislation	continious learning
-	teaching and training the others
-	knowledge and understanding of quality procedures related to digital transformation
-	negotiation skills
-	customer relationship management
-	leadership and managing others
-	adaptability and adapt to change
-	cultural empathy
-	work autonomously
-	appropriate linguistic skills
-	creativity
-	conflict resolution
-	climate change risk management
-	knowledge and understanding of international and national standards and legislation

In addition, due to the approach used in this research, the findings of the study will lead to the continuous development of the ESCO, and can thus be used more effectively by the end-users.

Furthermore, in order to confirm the validity of this research, the results were presented to the directors of the Inzu Group (INZU). We selected INZU as it is an internationally recognized industrial group formed by highly specialized companies from different sectors related to both Industry 4.0 and the Machine Tool sector. Among them, there are companies for the development of Industrial IoT (Aingura IIoT), Industrial Cyber-Security (Titanium), and many more enterprises related to the Machine Tool Sector (Etxe-Tar, Talens, Gaindu, Gurutzpe and Macarbox mainly). INZU showed interest in our work immediately; they analyzed the results of our research and ensured their validity. They evaluated the database and considered it as a functional element to support the strategy for the skills development of the human resources department in their machine tool companies.

4. Conclusions

The machine tool sector is one of the significant sub-sectors of the metal industry and the backbone of every single metal manufacturing operation. In recent years, emerging digitalization has deeply impacted the sector as manufacturing models have been constantly and profoundly changing with the application of smart technologies. The new phase of automation enables the machine tool producers not only to optimize processes and increase productivity but also to generate products with higher quality, reliability and performance and to offer better services to customers. Hence, Industry 4.0 may be considered as a crucial opportunity for the machine tool sector. Nevertheless, the only way for facing the challenges emerging with digitalization and converting them into advantages is to build a multi-skilled workforce capable of handling the implementation of new business models. Creating this high-qualified workforce is possible through (1) establishing a sectoral skills strategy (2) defining the foreseen skills requirements, (3) identifying the skills mismatch between the job profiles and the labor force (4) developing continuous and convenient training programs, (5) reskilling and upskilling of the workforce through well-developed training programs. In this work, we focused on steps (1) and (2). We first presented a sectorial strategic plan adapted from other sectors. After, we analyzed the

current skills needs and defined the expected evolution of skills requirements for the professional profiles of the machine tool industry. For this purpose, we generated an integrated sectoral database incorporating the current and near-future skills needs of selected professional profiles. During our research for identifying the job profiles related to the machine tool sector and their current skills needs, we used the ESCO database; for defining the future skills needs, we carried out detailed desk research and benefited from a wide range of respectable sectoral and cross-sectoral European frameworks, projects and publications combined with the compilations of subject matter experts' opinions. Thanks to our interaction with ESCO experts, the findings of this research will help the continuous development of ESCO and will be consistent with the ESCO framework, which is an important reference commonly used by the European labor market, education and training centers. It is our belief that the generated sectoral database is a fundamental tool and it is capable of guiding the sector through future industrial changes. Indeed, our research was already validated by the Inzu Group (INZU) which is an internationally acknowledged industrial group having several machine tool companies. Also, the generated database was acknowledged as a useful tool by this organization during the implementation of skills.

We believe that this research can be used as a guideline by the machine tool companies, policymakers, academics and training centers during the development of effective training plans to diminish the skills gaps between the curricula of the workforce and the demands of the industry.

Moreover, it is important to make good use of the synergies between the different EU initiatives to support machine tool companies and particularly SMEs in their digital transformation. Well-developed skills policies and well-directed supporting measures at EU and national levels also have critical importance for SMEs to upgrade the skills of their workforce. The machine tool producers need further encouragement and support from the policy-makers and training and education centers, to implement the needed skills and be able to benefit from the digital revolution.

The machine tool sector is currently seeking further research projects particularly focusing on the development of new skills due to the digitalization of the industry. The future lines of research could ideally be about the next steps of the skills strategy that we developed herein: such as the implementation of skills and designing the training programs. Therefore, our work can also serve as a roadmap for future studies in this area.

Supplementary Materials: The following are available at <http://www.mdpi.com/2075-4701/10/12/1665/s1>, Figure S1: an example tab of the automated database generated for the job profiles in the machine tool industry, Figure S2: a brief view of the automated database (in excel format) including the description, alternative names, ISCO numbers and current competences of the professional profiles related to the machine tool industry, Figure S3: a brief view of the automated database (in excel format) including future competencies needed by the professional profiles related to the machine tool industry.

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Abbreviations

ISO	The International Organization for Standardization
EDM	Electrical Discharge Machining
SME	Small or Medium-Sized Company
CPS	Cyber-Physical-Systems
IoS	Internet of Services (IoS)
M2M	Machine to Machine
CECIMO	European Association of the Machine Tool Industries
QA	Quality Assurance
AVM	Automated Virtual Metrology
AI	Artificial Intelligence
IoT	Internet of Things
VBA	Visual Basic for Applications
ESCO	European Skills, Competences, Qualifications and Occupations
ISCO	Standard Classification of Occupations
ILO	International Labor Organization
ICT	Information and Communications Technology
CEPIS	Council of European Professional Informatics Societies
CEN	European Committee for Standardization
ESSA	Blueprint “New Skills Agenda Steel”: Industry-driven sustainable European Steel Skills Agenda and Strategy
APPRENTICESHIPQ	Development and Research on Innovative Vocational Educational Skills Mainstreaming Procedures for Quality Apprenticeships in Educational Organisations and Enterprises
SMeART	Knowledge Alliance for Upskilling Europe’s SMEs to Meet the Challenges of Smart Engineering
SPIRE-SAIS	Skills Alliance for Industrial Symbiosis—A Cross-Sectoral Blueprint for a Sustainable Process Industry
METALS	Machine Tool Alliance for Skills
ACETECH	German National Academy of Science and Engineering

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