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Skills Needs of the Civil Engineering Sector in the European Union Countries: Current Situation and Future Trends

Tugce Akyazi [1,†], Irantzu Alvarez [2], Elisabete Alberdi [3,*,†], Aitor Oyarbide-Zubillaga [1], Aitor Goti [1] and Felix Bayon [4]

1 Department of Mechanics, Design and Organization, University of Deusto, 48007 Bilbao, Bizkaia, Spain; tugceakyazi@deusto.es (T.A.); aitor.oyarbide@deusto.es (A.O.-Z.); aitor.goti@deusto.es (A.G.)
2 Department of Graphical Expression and Engineering Projects, University of the Basque Country UPV/EHU, 48013 Bilbao, Bizkaia, Spain; irantzu.alvarez@ehu.eus
3 Department of Applied Mathematics, University of the Basque Country UPV/EHU, 48013 Bilbao, Bizkaia, Spain
4 Sidenor Aceros Especiales, SLU, 48970 Bilbao, Bizkaia, Spain; felix.bayon@sidenor.com
* Correspondence: elisabete.alberdi@ehu.eus; Tel.: +34-946-017-790
† These authors contributed equally to this work.

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Abstract: The construction sector has always occupied a strategic place in the European economy. The European construction industry suffered during the 2007–2008 global financial crisis, and today the sector is undergoing a recovery process. Among all the construction subsectors, civil engineering has the highest growth rate. Currently, the sector has to face profound industrial changes emerging with digital transformations (Industry 4.0), sustainability, climate change and energy efficiency. To promote the growth of the civil engineering sector and accelerate the recovery, we need to create a highly qualified and competent workforce that can handle the challenges coming up with the technological progress and global competitiveness. The main condition to achieve this capable workforce is to define the expected evolution of skills requirements. For that purpose, our work focuses on identifying current and near-future key skills required by the civil engineering occupations. To achieve this, we developed an automated sectoral database for the current and near-future skills requirements of the selected professional profiles. It is our belief that this sectoral database is a fundamental framework that will guide the sector through the future changes. We also believe that our research can be used as a key tool for construction companies, policy-makers, academics and training centers to develop well-designed and efficient training programs for upskilling and reskilling the workforce.

Keywords: civil engineering; construction sector; skills; future skills; Industry 4.0; digitalization; sustainability

1. Introduction

The construction sector has a strategic importance for many countries across the world. It delivers the buildings and infrastructure needed by the rest of the economy and society. The construction sector occupies an important place in the European economy, since it generates approximately 9% of the gross domestic product (GDP) and approximately 6% of employment [1]. The construction value chain incorporates a wide range of economic activities, starting from the extraction of raw materials, the manufacturing and distribution of construction products, going up to the design, construction, management and control of construction works, their maintenance, renovation and demolition, along with the recycling of construction and demolition waste [2]. Therefore, the construction sector plays a significant role in reaching the European Union's "Europe 2020 Strategy" goals for smart, sustainable and inclusive growth [3].

In recent times, the construction sector has been recovering from the impact of a major crisis (the 2007–2008 global financial crisis). It was one of the most severely affected sectors during this economic crisis. The damage was reflected in both the production and employment rates.

Even though this situation was general throughout Europe, the crisis particularly hit the countries with construction dependent economies, such as Spain. The case of Spain, in fact, is a good example to demonstrate the serious effects of the bursting of the real estate bubble. Employment in the construction sector started to collapse in 2007, due to an excessive contribution from the sector; and production fell down to smaller values than the European average. In Figure 1, we can also see that, in Europe, both the employment and production rates of the construction sector remained relatively constant during the last two decades [1]. Between 2007 and 2013, both indices suffered a drop. Nonetheless, in the last five years of the graph (2013–2019), both increased moderately: the employment rate nearly reached to its pre-crisis values in 2000 and the production rate has already exceeded the pre-crisis values of 2000. In addition, if we compare the employment and production rates of Spain with the ones of Europe (Figure 1), we can conclude that this situation is not homogeneous throughout Europe. In the majority of the countries, the production and employment levels have already returned to pre-crisis levels. Nevertheless, this is not the case for southern Europe countries (e.g., Spain, Portugal, Italy, France and Greece) [4]. In these countries, the employment and production rates of the sector have not even reached the values of 2010 [4]. Nonetheless, they are in the process of recovering and improving the conditions of the sector.

There are significant 'recovery rate' differences between the subsectors within the construction sector. The subsectors with the best growth expectations are railway infrastructures, followed by roads and hydraulic infrastructures [5]. Although it took the civil engineering sector longer to recover from the crisis, it is still growing more quickly than other construction subsectors. Civil engineering ranks as the most expansive medium-term subsector in the construction sector. It is expected that this sector will have the highest growth among all the construction subsectors in the coming years [6]. Therefore, in this work, we pick the civil engineering sector as the most representative subsector of the construction sector to develop our methodology.

The civil engineering sector is already undergoing a recovery process. However, to accelerate the recovery and promote the growth of the sector, we need to prepare the workforce for the future. Only a qualified and competent workforce can carry the civil engineering of today to the future, turning it into a more innovative and competitive sector. The main condition to achieve this competent workforce is to define the expected evolution of skills requirements. To make this possible, we first need to describe the factors affecting the skills requirements of the sector and carefully draw a general portrait of skills needs.

First, we need to acknowledge that for nearly 20 years, sustainable development has been one of the fundamental objectives of the European Union and The EU is taking this issue very seriously fully committing to it. The EU adopted a "Sustainable Development Strategy" in order to achieve the creation of sustainable communities which are able to use the resources efficiently, able to tap into the ecological and social innovation potential of the economy and ensure prosperity, environmental protection and social cohesion [7]. The EU is committed to implementing the 2030 Agenda for Sustainable Development and the Sustainable Development Goals (SDGs) within the EU and in development cooperation with partner countries [8]. On the other hand, buildings, infrastructure and construction products have an important impact on energy and resource efficiency, the fight against climate change and in the environment in general [2]. Buildings account for the largest share of total EU final energy consumption (40%) and produce about 35% of all greenhouse emissions [9]. Moreover, the construction industry is the single largest global consumer of resources and raw materials [10,11]. Particularly, transport infrastructure has a significant impact on the environment. Infrastructure networks and civil engineering in general require a substantial consumption of energy and raw materials, and produce a large volume of waste. Therefore, the civil engineering sector is a strategic sector to face the challenges of today's society, such as the climate emergency, the reduction of energy consumption and the sustainable use of resources. Overall, the sector plays a critical role in achieving a more sustainable Europe. As a result, the European Commission developed a strategy, "Construction 2020", for the sustainable competitiveness of the construction sector and supported its adaptation to the main challenges of the future [3]. This strategy focuses on five objectives: investments financing (investment and digitalization), jobs (skills and qualifications), resource efficiency, regulation and market access (competition). It emphasizes that a more innovative and competitive civil engineering sector will create infrastructures adapted to social and economic needs; it will face the challenges of energy security and climate change, and it will offer good working conditions, with opportunities for career development, offering health and safety at work as well as appropriate salaries. Therefore, the incorporation of sustainability, energy efficiency and adaptation to climate change (along with Industry 4.0 which is explained next) are the key factors that affect the competitiveness of the sector. Thus, the sector requires further research into new materials and more sustainable, energy efficient construction methods. Even more importantly, there is an urgent need for the development of new skills related to sustainability, measures about climate change and energy efficiency. Consequently, the green skills are crucial for the civil engineering sector; the sector will expect from its near-future workforce to have expertise in green skills such as resource efficiency (sustainable resource management), energy consumption, material reutilization and recycling, waste reduction, life-cycle analysis, environmental awareness, etc.

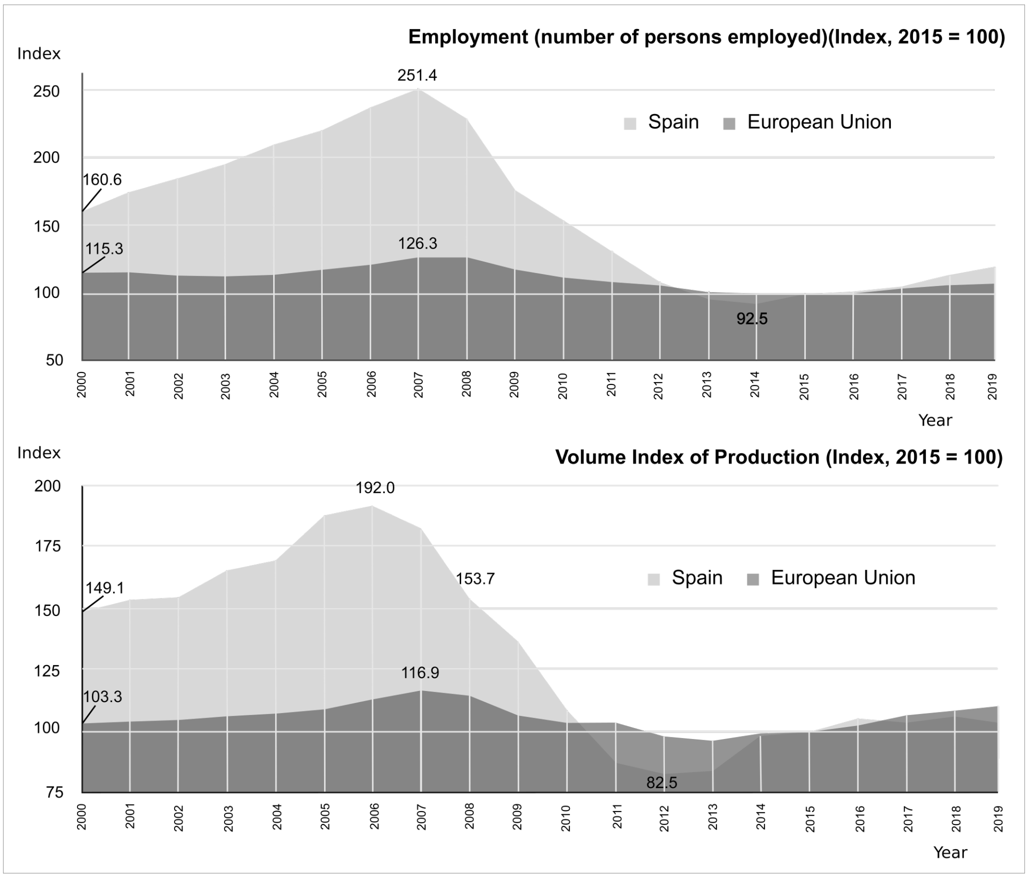

Figure 1. Production and labor input in construction: Eurostat, production in construction (annual data) [1].

The fourth industrial revolution, Industry 4.0, is the other main factor that directly affects the competitiveness and future skills needs of the construction sector. The term "Industry 4.0" refers to the novel manufacturing processes that are partially or entirely automated through the technological innovations which enable the machines along the value chain to share information with each other in an autonomous way [12–14]. The digital transformation is the foundation of the current industrial revolution [15,16]. The emerging digitalization is profoundly altering the dynamics of almost all industries. The development of the smart digital technologies (e.g., Artificial Intelligence (AI), Machine Learning, Big Data, advanced robots, Internet of Things (IoT), etc.) facilitates a new phase of automation for the industry. Innovational, higher quality and more efficient processes, products and services are achieved through the integration of these smart technologies [13,17].

Industry 4.0 can be acknowledged as an exceptional opportunity for the recovery and growth of the construction industry. However, the construction industry has been hesitant to embrace digital innovation [18]. As a result of the underinvestment in R&D and innovation, its labor productivity has hardly grown, at a quarter of the rate in manufacturing over the past two decades [19,20], and it might fall behind in the race for innovation if the level of digitalization does not improve in the construction industry [18]. The sector has already introduced some 4.0 technologies through the whole construction value chain [21]. Nevertheless, the construction companies need to integrate more of these technologies in their processes and daily operations, maximizing their use of digital innovations and automation, thus transforming their business models. European policy-makers who are aware of this gap have already developed policies and taken actions aiming to facilitate the integration of digital technologies and promote a digital innovation in the construction sector [7,8,18,20]. One of the main focuses of the European Construction 2020 Strategy (mentioned above) is digitalization. Moreover, the incorporation of the research activities and technological innovations along the construction value chains is also supported and promoted by other significant EU policies and (financial) instruments such as the Cohesion Policy, the Horizon 2020 and Competitiveness of enterprises and SMEs (COSME) 2014–2020 [2,3,18].

Smart and innovative 4.0 technologies would enable the construction sector to build in a faster and superior way and at lower costs, while maximizing resources use and increasing the profitability. They have a potential to make a major impact on the construction sector [18]. Some of these innovations are Building Information Modelling (BIM), the Internet of Things (IoT), 3D laser scanning and component printing, big data analytics, augmented reality (AR), robotic construction, artificial intelligence (AI), sensor systems, intelligent materials, drones, etc. along with further research into new materials and methods also provide great support to the construction industry looking for solutions regarding the new climate, energy and environmental challenges [3,22].

BIM has become the main system to store digital information about a project related to construction or civil engineering [21]. It is taking the center position in the digital transformation of the construction industry [23,24]. In addition, it is designed to promote the quality, the efficiency and the productive capacity of construction [25]. BIM is a digital tool for integrated design, modeling, planning and integrated collaboration, which provides all people related to any of these phases with a digital representation of the characteristics of a building throughout its life cycle [24]. This exchange of information facilitates collaboration between different phases of the project, and, as a consequence, it allows increasing the efficiency as well as reducing the costs. Despite being very useful for the construction industry, BIM is adopted by the sector in a fragmented manner [18]. It is commonly utilized by architects, engineers and occasionally by contractors; nevertheless, operation and maintenance professionals have hesitations to use it and they have so far shown limited interest in integrating this digital technology in their process, therefore not allowing the sector to take full advantage of the benefits that BIM can provide [18]. Accordingly, European policy makers are promoting the use of BIM through the whole construction value chain. In Spain and in Europe, several regulations were established to implement this work methodology. In 2014, the European Parliament issued the Directive 2014/24/EU [24] whereby it urges member countries to implement the BIM methodology in all those construction projects financed by public funds. In Spain, the Public Sector Contract Law [25] establishes the use of BIM in public building tenders since December 2018, and in public infrastructure tenders since July 2019. In addition, worldwide, universities are gradually incorporating BIM methodology in their civil engineering teaching programs, encouraging teachers to develop more realistic, practice oriented educational examples and preparing the students to face with future challenges more efficiently [26–28]. The technologies that can be integrated within BIM are those related to the acquisition of terrain data (3D scanners, drones, etc.), 3D printers and AR. The representation of natural phenomena and technical structures in civil engineering can be created using computer-based simulation models. This approach provides a considerable potential for the augmented reality (AR) applications in the sector [29,30]. The virtual reality (VR) simulators have been presented as a tool train for providing risk-free training for the construction workers. However, VR is still a developing technology. It is too expensive and complicated to use for the average user. Some of its biggest limitations are that it can only be used by one person at a time and that it isolates the user from the real world. In this way, it limits the user's work environment to the virtual world, where interaction with others is limited to other people sharing the same virtual world and, therefore, requiring additional VR devices. These are the reasons the use of AR is increasing and it is quickly overtaking VR in the construction sector [31]. While VR builds a new environment which is entirely independent of the real world, AR consists of the virtual elements which actively interact with the elements that are present in the real world [32,33]. Thanks to AR, virtual architectural designs can be merged with the reality of the construction site. This enables users to improve efficiency and accuracy, reduce errors and save time, money and resources [32]. AR can considerably improve the design and planning process, progress monitoring and provide support for construction operations (building, maintenance, repair and inspection) [33]. It can drastically increase safety on the construction site. AR ensures a very effective training using the actual equipment. It has a high potential especially in safety and equipment operator trainings for workers [30] as well as teaching the students in civil engineering schools [29,34]. It also allows the project managers and engineers to prepare a more detailed and accurate safety plan [30]. It also enables the users to execute precise measurements including height, width and depth in the site. It is also possible to make on-site revisions and identify problems using AR. Correcting these errors proactively saves a considerable amount of time for the users. Moreover, augmented reality (AR) technology via wearable devices can be further improved through the adoption of 5D BIM technology. It has the potential to transform the whole construction industry [31]. Using AR, a virtual overlay of a BIM model can be overlapped on the actual construction site and contractors or project managers can compare them on site in real time. [30]. The integration of built environment AR, with real-time data from IoT devices, also presents a unique opportunity for the sector to increase operational efficiencies and support decision-making [33].

The relentless trend in sophisticated automation, sensor deployment, monitoring and control in construction highly increases the potential for IoT applications in the civil engineering sector [35,36]. The IoT technology enables construction equipment, machinery, structures, etc. to be connected through a central data platform [31,37]. It is common also the analysis of massive data with tools such as Big Data, Data Analytics, Machine Learning, fed with data that come from infrastructures and buildings in real time using IoT [11,38].

The mechanics of automation and the applications of sensors have been deeply examined for robotic construction and extensive use of sensors [39,40], despite the fact that their teaching in civil engineering schools is not still widely spread [35]. Sensors on site can be effectively deployed for the safety of the workers through monitoring temperature, dust particles, noise levels, etc. and limiting workers' exposure to them [30]. Nevertheless, sensors technology is usually used for a more general reason in this sector: to monitor productivity and reliability through tracking all the relevant movements in the construction site. Once sufficient amount of data is collected through sensors, AI can analyze the data and provide solutions to rearrange the equipment and materials in order to make them more accessible to workers and increase efficiency [41]. AI and autonomous drones are also adopted for real-time monitoring of the construction site progress in order to increase the productivity, evaluate the quality and decrease downtime [30,41]. Deep-learning algorithms are then applied to identify any kind of errors in the executed work. AI also recognizes the deviations between the installed components and the actual work with models so the errors can be determined instantly and the high costs of a rework is avoided. In addition, through AI and machine learning, companies can put the data they have collected throughout the years to use in order to predict how projects will work out, and therefore better estimate and bid on construction projects [30].

Robotics systems are capable of transforming the construction industry, presenting numerous advantages for the sector [42]. In the near future, robots are expected to become one of the dominant technologies in the construction sector with their offering of accuracy and precision [31,42,43]. The robotic systems which are commonly being used in the sector nowadays are single task construction robots (STCRs). They carry out a single task repetitively [30,44] and this task is only a simple one. Nevertheless, once they are set up, they can work non-stop without needing a break and help the workers to complete the task more quickly. Some examples are bricklaying robots [45,46], rebar tying robots [45], painting robots [47] and concrete spraying robots [48]. In these examples, human intervention is needed to set up the robot, to place it correctly, to start the system, to clean it up, to oversee the performed work, etc. [30,44]. Therefore, the aim of most construction robots is not to replace workers, but to help them, increasing their performance and, overall, making them more productive [30]. Aforementioned STCRs are useful and flexible since they can be easily integrated in conventional construction procedures. They also have some challenges. Some of their drawbacks are that their application demands new health and safety requirements and that it leads to some difficulties during the human workers' incorporation [30]. Several studies were carried out to address these challenges [49,50]. In these studies, various STCRs which perform different tasks are integrated into a construction site. Then, a networked robotic system was created using a hardware-software system [44,49,50]. Although this kind of on-site robotic factories has already been built and tested successfully, they are still in the development stage where it is still too early for the construction industry to adopt them.

Autonomous heavy equipment (self-driving construction vehicles) is actively being used in the construction sites to execute various tasks [30]: autonomous track loader (ATL) for light construction work, autonomous dozer for pushing heavy objects and leveling soil, autonomous excavator for excavation, loading rucks, digging trenches, etc. [51] They possess similar technology for self-driving cars including light detection and ranging sensors, augmented GPS and drones [30,51]. This technology makes machines totally autonomous, freeing workers from operating them, so companies can cover more tasks with the same personnel, increasing productivity. They also eliminate the human error as much as possible and prevent accidents related to construction equipment operators.

Overall, in the next decades, more extensive adoption of robots and autonomous equipment is expected in the sector. Since the construction industry is one of the most dangerous industries, the main aim of these technologies other than increasing productivity will be improving safety. The workers within the next decade are going to be expected to operate these machines and use the relevant technologies to perform their jobs [30].

Materials science and technology plays a significant role in the progress of the construction industry. Novel building materials enable contractors to create more sustainable, energy-saving, eco-friendly, smart and resistant structures. In addition, building materials represent a 1 trillion dollars global industry [31]. They can reduce costs, speed up construction, enhance the safety and improve the quality of the building [31]. The latest trend points to using green products as well as integrating renewable and natural resources in the industry. Most of them are relatively affordable, whereas a few others are costly due to their high fabrication costs. Every new generation material has excellent properties (e.g., being self-sustaining, recyclable, smart, lighter, stronger, etc.) and most of them are designed to last for centuries. Some of the most recent materials that have caused a big impact in the construction industry are the following: self-healing concrete [52,53] (reduces infrastructure maintenance and the production of greenhouse gases and decreases construction costs), hydroceramics [54] (cool the building and lower energy costs), wool bricks [55,56] (stronger, lighter, more sustainable and eco-friendly alternative), 3D graphene [57] (considered a future replacement of steel, having 5% of steel's weight and offering up to 200 times its strength), transparent aluminum [58] (translucent, rigid, corrosion and radiation resistant and ideal for future space vehicles, resistant windows, etc.), nanocrystals [59,60] (used in smart windows since they let natural light through while blocking heat, reducing energy costs), aerogels [59,61] (nano-level lightweight foams with very low thermal conductivity, provide insulation and lower the production of greenhouse gases and energy costs), light generating cement (reduce lighting costs) [62,63] and air cleaning bricks [64] (able to filter 30% of fine particles and 100% of coarse particles and a cost-effective and efficient way to lower pollution levels).

The other promising digital innovations in the construction sector are 3D printing, drones and 3D laser scanning. 3D printing in the construction sector refers to the manufacturing of buildings layer-by-layer through melting and ejecting materials such as polymers, ceramics, metals, concrete, etc. by an automated machine, based on digital 3D models [65]. Unlike the other innovations related to the design, engineering, operations of the construction, etc., 3D printing is mainly taking place in the actual construction phase. It reduces the cost of construction due to zero waste, it uses recycled materials (resource efficiency) and it decreases the use of transport [66]. It also grants flexibility to architects allowing to fabricate complex shapes. 3D printing also responds to one of the key concerns in European construction sector, the concern about the construction labor shortage, through shortening construction time and maximizing resources use [18]. On the other hand, drones are already being used actively by the construction companies along the value chains [67]. Indeed, their application has been one of the most attractive trends in the construction sector recently [68]. Drones are considered important particularly for their capability to provide cheap and efficient ways for the mapping of construction sites [18,68–70]. They enable real time accurate data exchange between different construction value chain actors [18,68,70,71] and collecting three-dimensional information (which can be integrated within existing BIM systems) [68,70,72]. They can also perform tasks such as site inspections and building surveys that will cause the field personnel to be exposed to less risk [18,68,70,72–75]. The other technology, 3D laser scanning (high-definition surveying (HDS) or reality capture), is used to obtain an accurate information of a construction site. During the site design, it is a starting point since many projects get delayed to the ground conditions [31,76]. Due to its accuracy, it enables the construction teams to make a very detailed plan on the site and improves the quality of the work. Since this method provides data instantly (much more quickly than traditional methods), it saves time and money, upgrades operations, streamlines productivity, reduces the amount of errors and rework and leads to faster and better overall decision-making [76]. Laser scanning is gradually becoming a norm on the construction sites due to its advantages.

Overall, although the integration of digital innovations in the construction industry is still not as widespread as in other sectors, in the near future, the workforce will undoubtedly need to develop new technological and transversal skills. The main consequence of the aforementioned current and potential technological changes in the construction sector is the high demand for technological skills, including not only basic but also advanced digital skills such as programming, BIM, 3D drawing programs, etc. [77–80]. The use and development of software will be required in all the fields of civil engineering. Indeed, Programming, 3D drawing programmes, simulation applications are already routinely used in civil engineering [35,81–83]. Moreover, data security and data protection will be crucial [13,39–78]. Since automated machines are far from learning social and emotional skills, soft skills will gain importance as the level of digitalization increases [77–80]. As the adoption of the innovations increases, simple and monotonous tasks will be carried out by automated machines and the workforce will be in charge of more complex tasks and they will be asked to make critical decisions [78,80]. To execute qualified work, the workforce will need not only solid literacy, numeracy, problem-solving and ICT skills but also soft skills such as autonomy, collaboration and coordination [79,80]. Teamwork between co-workers will be essential; managerial, communication and organizational skills will also gain significant importance [78–80]. Additionally, the development of additional individual competences such as appropriate linguistic skills (it often refers to speaking a global language), cultural empathy and conflict resolution skills is considered essential for a multinational work environment [84,85]. Cultural empathy can be defined as the recognition of difference in perspective resulting from cultural contrast, and the latter embodying attitudes such as flexibility, adaptability or tolerance [85]. The workforce will also be expected to have higher cognitive skills such as critical thinking, problem-solving, creativity, complex information processing, life learning, etc. [13,78,86]. Risk management—the ability to identify and assess project risks and mitigate threats—has already become crucial for white-collar workers in the civil engineering sector [87–90]. Moreover, the intellectual competences (e.g., comprehension, reasoning, analyzing and problem solving) are as important as the ethical ones, since they would improve the self-confidence of the workers and their ability to make decisions and take risks, engage in reasonable discussions and formulate questions [91]. The development of ethical competences as well as the intellectual capabilities would improve the self-confidence of the workers, their ability to make decisions and take risks, engage in reasonable discussions and formulate questions [91]. The general trend points that the European construction workforce will have a greater need for technological, social, emotional and higher cognitive skills as a result of Industry 4.0.

In conclusion, the European civil engineering sector needs to update the qualifications of its workforce so that it can grow progressively and be a competitive industry—as it used to be. Through this update process, the sector can create a multi-skilled and competent workforce which can handle all the challenges related to digital transformation sustainability, measures about climate change and energy efficiency [13,17] To accomplish a successful upskilling and reskilling of the labor force, the sector first needs to analyze the current skills requirements and then identify future skills needs. (Our work represents particularly these two steps.) Once the skills gap (gap between what the current workforce offers and what the sector expects from the workforce) is identified, the sector would develop specialized training and education programmes, in order to reduce this gap [13,17].

The construction sector is in urgent need of a roadmap for meeting the future skills demands. We developed this work to address the present need. Our work focuses on determining the current and near-future skills needed by the job profiles related to civil engineering sector. We chose "civil engineering" sector as the representative subsector of the construction engineering due to the reasons represented in this section. In addition, we analyzed the approaches taken by other industries (e.g., steel, automotive, etc.) and adapted them to the civil engineering sector during the development of the tools for implementing new skills. In particular, we benefited from the ESSA project through adapting its methodology to the civil engineering sector during the analysis of current and future skills. We adopted the European Skills, Competences, Qualifications and Occupations (ESCO) database as the main reference for defining the current civil engineering occupations and the skills required by each occupation. Afterwards, we developed an automated database incorporating the definition of the selected occupations and the skills currently demanded by them in the excel format. Then, we carefully analyzed each of the professional profile in the database and selected the ones who would go through a transformation due the industrial changes facing the sector. As the next step, we identified the most significant (generic and specific) future skills for the civil engineering sector through a detailed study. During this process, we benefited from respectable European frameworks, strategic sectoral and intersectoral European projects as well as substantial scientific studies. Then, we examined and determined which future skills will be needed for each profile and added the outcome to the created database. Eventually, we created an automated database involving the current and near-future skills requirements for the civil engineering professional profiles. This database can be used as a key framework by the construction companies, training centers, universities and policy-makers who are in charge of providing the well-designed training programs to deliver the desired skills to the sector's labor force. It is our belief that the work we are developing will be a crucial tool for the construction industry. It will provide the main guidelines for the sector leaders and training providers to rebuild the workforce and meet the future skills needs.

2. Materials and Methods

The research methodology used in this study combines desktop research and contrasts with inter-sectoral subject matter experts for both the identification and the prioritization of skills and competences for each job profile. Thanks to this methodology, the results of the research will contribute to the continuous improvement of ESCO, are compatible with the ESCO structure and can therefore be used more easily by anybody.

2.1. Professional Profiles of Civil Engineering and Their Current Skills

During the selection and the classification of the civil engineering professional profiles, the analysis of their current skills needs and the development of the database introduced herein, we utilized the ESCO database as the main data source. ESCO is the European Multilingual Classification of Skills, Competences, Qualifications and Occupations. It serves the end-users as a dictionary that defines and categorizes occupations, skills, competences and qualifications which are consistent and suitable for the European job market, education and training [92]. ESCO offers a "common language" on occupations and skills that can be used by different stakeholders on employment and education and training topics in Europe [92]. It is also directly connected with a significant international framework, the International Standard Classification of Occupations (ISCO). ISCO is a categorization of occupations and occupational groups achieved by the International Labor Organization (ILO).

Moreover, during the development of the automated database of the civil engineering professional occupations, we used Microsoft Visual Basic for Applications (VBA) for Excel as the programming language .

2.2. Future Skills Requirements

We identified the future skills using several respectable sources. In the Introduction, we analyze the factors (next innovations and industrial changes) affecting the skills needs of the sector and achieve a general idea of the future skills requirements. This analysis was carried out using several EU reports related to construction sector, as well as some international scientific publications [2,3,7–92]. In our research, during the selection of the most relevant future skills, we benefited from this desk research.

To identify the future skills needs, we used different strategic sectoral and cross-sectoral European projects as a source, in some of which we directly took part or carried out tasks as collaborators: ESSA (steel sector) [93], SPIRE-SAIS (cross-sectoral) [94], DRIVES (automotive sector) [95], APPRENTICESHIPQ (Procedures for Quality Apprenticeships in Educational Organisations) [96] and SMeART (Digitalization of Small and Medium Enterprises, SMEs) [97]. Nevertheless, we used the work which was carried out in the ESSA project as our main reference. The project is dedicated to the development of a Blueprint for "New Skills Agenda Steel", is entitled "Industry-driven sustainable European Steel Skills Agenda and Strategy (ESSA)" and funded by the European Union through the Erasmus Plus framework. The agenda aims to present a strategy for meeting current and future skills demands, and pilot the development of modules and tools for building awareness and implementing new skills for a globally competitive industry. The aim is to be ready to anticipate new skills demands and develop pro-active practical activities to meet the future requirements of the industry. The project also develops approaches to sustain an environmentally responsible industry and promotes sustainable growth, innovation and the creation of highly skilled jobs.

We also benefited from the European ICT Professional Role Profiles framework [98] (developed by the Council of European Professional Informatics Societies (CEPIS) [99] and European Committee for Standardization (CEN)) [100], the work of the European Civil Engineering Education and Training (EUCEET) Association [101] and the research carried out by McKinsey Global Institute [19,20,78]. CEPIS is a not-for-profit association devoted to building a high standard among professional occupations related to informatics. recognizing the profound effects of informatics on employment, business and society [99]. CEN is an organization that gathers 34 different National Standardization

Bodies in Europe promoting standardization operations related to a broad spectrum of areas and sectors [100]. The European ICT Professional Role Profiles framework was achieved by the contributions of the above-mentioned two organizations. It was developed as a contribution to a shared European reference language for identifying, organizing and handling current and future ICT professional needs and to improving the ICT professions overall [98]. EUCEET Association aims to promote the development of education and training programmes in civil engineering, particularly those related to innovative approaches; to encourage cooperation between higher education institutions teaching civil engineering; to help building up an educational criteria in civil engineering, based on learning outcomes and competences; and to cooperate with other international organization from Europe and outside Europe [101]. It has many higher education institutions from different non-EU countries (e.g., Turkey, Russian Federation, Ukraine, Taiwan and Albania) as members [101]. Therefore, the association is able to provide a considerable amount of data to improve the European civil engineering education.

Moreover, the selection of the green skills was performed by a panel of experts of the SPIRE-SAIS project.

3. Results and Discussion

3.1. Professional Profiles in Civil Engineering and Their Current Skills

The main objective of this research was to develop an automated database of the (current and future) skills requirements for the occupations in the civil engineering industry.

For this purpose, we first identified and selected the job profiles related to civil engineering in ESCO database in excel format. We picked the traditional profiles which are directly linked with and specific for civil engineering sector. Once we integrated the selected profiles into a word excel file, we generated an automated database using VBA. The created database incorporated only the current skills requirements for the professional profiles.

To analyze the skills needs more effectively, we classified the occupations into ten groups depending on the kind of tasks and the level of qualification and autonomy that are expected from them. As shown in Table 1, they were categorized according to the tasks assigned to each professional profile within the life cycle of civil engineering projects: design, execution and maintenance. The professional profiles related to design, planning and development of the projects are civil engineers, technicians and draftsmen (Profiles 4, 8 and 9 respectively), having different degree of responsibility in the project. These are the most qualified profiles having a higher degree of responsibility. The job profiles in charge of execution can be classified in two groups: those who prepare the ground (Profile 1) and the technicians in charge of all the tasks related to the management of the necessary machinery (Profiles 2, 3, 5, 6 and 7). In Table 1, ten different professional profiles are presented with their definitions.

As the next step, we analyzed the current knowledge and skills of the aforementioned ten occupations using the database based on ESCO. We also identified the current competences that can respond to future needs of the civil engineering (these future needs which are caused by the innovations and industrial changes are described in the Introduction). In Table 2, in the first column, we can see a sample of essential skills needs of today and in the second column, we can observe the current skills and knowledge requirements that are compatible with the future scenario.

Table 1. Professional profiles related to civil engineering.

Group	Professional Profile	Definition
Profile 1	Civil engineering workers	They perform tasks concerning the cleaning and preparation of construction sites for civil engineering projects. This includes the work on building and maintenance of roads, railways and dams.
Profile 2	Import export manager in mining, construction and civil engineering machinery	They install and maintain procedures for cross-border business, coordinating internal and external parties.
Profile 3	Mining, construction and civil engineering machinery distribution managers	They plan the distribution of mining, construction and civil engineering machinery to various points of sales.
Profile 4	Civil engineers	They design, plan and develop technical and engineering specifications for infrastructure and construction projects. They apply engineering knowledge in a vast array of projects, from the construction of infrastructure for transportation, housing projects and luxury buildings to the construction of natural sites. They design plans that seek to optimize materials and integrate specifications and resource allocation within the time constraints.
Profile 5	Rental service representative in construction and civil engineering machinery	They are in charge of renting out equipment and determining specific periods of usage. They document transactions, insurances and payments.
Profile 6	Import export specialist in mining, construction, civil engineering machinery	They have and apply deep knowledge of import and export goods including customs clearance and documentation.
Profile 7	Wholesale merchant in mining, construction and civil engineering machinery	They investigate potential wholesale buyers and suppliers and match their needs. They conclude trades involving large quantities of goods.
Profile 8	Civil engineering technicians	They help design and execute construction plans and take on organizational tasks, for example in the planning, monitoring, bidding and invoicing of construction work. They also calculate material requirements, help with the purchasing and organizing and ensure the quality of the construction materials. Civil engineering technicians may perform technical tasks in civil engineering and develop and advise on policy implementing strategies for road works, traffic lights, sewerage and water management systems.

Table 1. *Cont.*

Group	Professional Profile	Definition
Profile 9	Civil drafters	They draw and prepare sketches for civil engineers and architects of architectonic projects of different kinds, topographical maps, or for the reconstruction of existing structures. They lay down in the sketches all the specifications and requirements such as mathematical, aesthetic, engineering and technical.
Profile 10	Land surveyor	Land surveyors determine, by means of specialized equipment, the distances and positions of points at the surface of sites for construction purposes. They use measurements of the specific aspects of construction sites, such as electricity, distance measurements and metal structure volumes to create architectural drawings and develop construction projects.

Except Profile 7, which does not have any kind of current skills related to future trends at all, only a few of the current competences can respond to the rest eight profiles to future needs in the upcoming scenario. These skills are not sufficient to reflect the future trends of the civil engineering sector. There are no competences about the new Information and Communications Technology (ICT) applied to the sector (BIM, IoT, 3D printing, etc.) [98] or those related to the adaptation to climate change and the reduction of waste and energy expenditure. In some cases, as in the case of Profile 4, they appear as optional skills, whereas they should have been considered mandatory.

Table 2. Current skills and knowledge in each professional group.

Group	Sample of Current Skills	Skills and Knowledge That Respond to Near-Future Requirements
Profile 1	Dig soil mechanically; follow health and safety procedures in construction; guide operation of heavy construction equipment; inspect asphalt, construction sites and supplies, and drainage channels; and use safety equipment in construction.	Optional skill: Use measurement instruments.
Profile 2	Abide by business ethical code of conducts; apply conflict management; build rapport with people from different cultural backgrounds; comprehend financial business terminology; conduct performance measurement; control trade commercial documentation; and create solutions to problems.	Essential skills: Have computer literacy; monitor international market performance; and speak different languages.
Profile 3	Adhere to organizational guidelines; carry out inventory control accuracy; carry out statistical forecasts; communicate with shipment forwarders; create solutions to problems; and develop financial statistics reports.	Essential skills: Perform financial risk management in international trade and perform multiple tasks at the same time.

Table 2. *Cont.*

Group	Sample of Current Skills	Skills and Knowledge That Respond to Near-Future Requirements
Profile 4	Adjust and approve engineering designs; ensure compliance with safety legislation; perform scientific research; and use technical drawing software.	Essential skills: Use technical drawing software. Optional knowledge: Energy efficiency; energy market; energy performance of buildings; environmental engineering; environmental legislation; environmental legislation in agriculture and forestry; renewable energy technologies; and zero-energy building design. Optional skills: Carry out energy management of facilities; carry out environmental audits; collect data using GPS; create AutoCAD drawings; create GIS reports; use a computer; use CAD software; and use geographic information systems.
Profile 5	Achieve sales targets; apply numeracy skills; assist customers; communicate with customers; guarantee customer satisfaction; and handle financial transactions.	Essential skills: Process data.
Profile 6	Administer multi-modal logistics; apply conflict management; apply export strategies; apply import strategies; build rapport with people from different cultural backgrounds; and communicate with shipment forwarders.	Essential skills: Have computer literacy.
Profile 7	Assess supplier risks; build business relationships; comprehend financial business terminology; have computer literacy; identify customer's needs; identify and new business opportunities.	No skills of this type.
Profile 8	Ensure compliance with safety legislation; estimate duration of work; follow health and safety procedures in construction; inspect construction supplies; keep records of work progress; and perform field research.	Essential skills: Use technical drawing software. Optional knowledge: Energy efficiency and energy performance of buildings. Optional skills: Create AutoCAD drawings; promote environmental awareness; and use CAD software.
Profile 9	Create technical plans; read engineering drawings; use CAD software; use manual draughting techniques; and use technical drawing software.	Essential skills: Use CAD software and use technical drawing software. Optional skills: Render 3D images and use geographic information systems.
Profile 10	Adjust surveying equipment; conduct land surveys; determine boundaries; ensure compliance with safety legislation; operate surveying instruments; perform surveying calculations; prepare surveying report; record survey measurements; and use technical drawing software.	Essential skills: Use technical drawing software. Optional skills: develop geological databases; use CAD software; study aerial photos apply digital mapping; collect data using GPS; and compile GIS-data.

3.2. Future Skill Requirements in Civil Engineering

After generating the database of the civil engineering occupations and their current skills needs using ESCO, our next step was to identify and incorporate the future skills requirements into our database.

ESCO database is a very useful source for classifying the skills, competences, qualifications and occupations. Nevertheless, it needs to be enriched regarding future skills due to the natural evolution of occupations. It does not provide us an adequate input about the new skills needs caused by the industrial changes and innovations in the sector. In addition, it does not involve transversal skills which are considered as fundamental for tomorrow's workforce in every sector including civil engineering. Therefore, in our research, we used other references to deal with future skills demanded by the civil engineering sector.

To identify the future skills and competences, we carried out a desk research about the future skills trends of the civil engineering sector (see Section 1). It gave us a general but a clear idea about what kind of additional skills should be expected from the workforce in order to achieve a sustainable competitiveness and a successful digital transformation. We also concluded that these new skills can be mainly classified as digital skills, green skills and transversal skills.

We adopted the methodology that we had developed in ESSA project; we picked the most relevant skills from the research executed by McKinsey Global Institute and EUCEET association, the SPIRE-SAIS project and the European ICT Professional Role Profiles framework. Then, we identified more future skills that will be demanded particularly by the civil engineering occupations through carrying out an elaborate analysis (benefiting from the aforementioned desk research). Eventually, we achieved a final list of the future skills needs for the civil engineering workforce. Tables 3 and 4 demonstrate this final list. Table 3 shows new generic skills, whereas Table 4 demonstrates new specific skills for the civil engineering sector.

Before adding the identified future skills to the database, we initially needed to determine the professional profiles that would need an updated curricula with additional knowledge and skills. For this purpose, we examined all the professional profiles one by one and chose the ones which will be changed by the technological progress or sustainability requirements. We also collected data from the aforementioned sectoral and inter-sectoral European projects to interpret what kind of professional profiles in these sectors have undergone changes. Then, we identified job profiles related to civil engineering with equivalent roles in different sectors (e.g., import export manager, draftsmen, project manager, recycling specialist, waste technician and machine operator) that have already undergone transformations. Moreover, the European ICT Professional Role Profiles framework granted us the particular professional occupations of which skills have been altered through digitalization. Tables 3 and 4 provide us the needed future skills for the ten groups of occupations through a detailed analysis. If we analyze Tables 3 and 4 carefully, we can see that several of the future skills in them are also the fundamental skills of a software developer, industrial engineer, environmental engineer or project manager. This demonstrates that the next generation of professionals in the civil engineering sector will need to be multi-skilled and highly qualified.

As the final step, we integrated the future skills and competences to our database and updated the skills requirements for the transformed occupations. We finally achieved an automated database for the civil engineering occupations, incorporating both the current and future skills requirements.

Figure 2 shows an example tab of the generated database. In this table, we can see "civil engineer" professional profile as an example. The first four rows of the table demonstrate a hierarchical order of the occupational groups; being the first row "professionals" the biggest and the fourth row "engineering professionals" the smallest group that the profiles belong to. We can also see a link to ESCO's webpage where all information presented herein about the occupation is available. Additionally, we can recognize the alternative names used for referring the same occupation. The database also provides the ISCO number of the profile, which can be described as an international code of the occupation for ISCO. Moreover, the table demonstrates not only the knowledge and skills currently needed by the professional occupation (extracted from ESCO database), but also the future skills that we introduced through our research. The future skills are shown in bold. The complete version of Figure 2 is attached in the Supplementary Materials (Figure S1). In this excel table, if we change "civil engineer" profile to another job profile, all the information about the new profile comes into sight automatically, replacing the data associated with "civil engineer" profile. Therefore, this is called a smart table and it can be achieved by the automation of the database. This technology makes the database a very efficient and useful tool for preparing well-established training and education programs.

Table 3. Near-future skills for each profile: Generic skills.

Generic skills	**Profile 1**	**Profile 2**	**Profile 3**	**Profile 4**	**Profile 5**	**Profile 6**	**Profile 7**	**Profile 8**	**Profile 9**	**Profile 10**
Inspecting and monitoring skills		x	x	x		x	x	x	x	x
Basic digital skills	x	x	x	x	x	x	x	x	x	x
Advanced data analysis		x	x	x		x	x	x	x	x
Mathematical skills				x				x	x	x
Cybersecurity		x	x	x	x	x	x	x	x	x
Use of complex digital communication tools		x	x	x		x		x	x	x
Advanced IT skills & Programming				x				x	x	
IoT	x			x				x	x	x
Big Data	x	x	x	x		x		x	x	x
Artificial Intelligence (AI)				x				x	x	x
Sensors technology	x			x				x		x
Augmented Reality (AR)	x			x				x	x	x
Machine Learning				x				x	x	x
Business Intelligence		x	x	x	x	x	x	x	x	x
Information Security Management		x	x	x		x		x		x
Advanced communication skills		x	x	x	x	x	x	x		
Advanced negotiation skills		x	x		x	x	x			
Interpersonal skills and empathy		x	x	x	x	x	x	x		
Leadership and managing others		x	x	x		x				
Entrepreneurship and initiative taking	x	x	x	x						
Adaptability and adapt to change	x	x	x	x	x	x	x	x	x	x
Continuous learning	x	x	x	x	x	x	x	x	x	x
Teaching and training others	x			x				x		
Critical thinking and decision making		x	x	x		x	x	x	x	x
Personal experience		x	x	x		x	x	x	x	x
Ethical skills	x	x	x	x	x	x	x	x	x	x
Cultural empathy	x	x	x	x	x	x	x	x	x	
Work autonomously		x	x	x		x	x	x	x	x
Active listening		x	x	x	x	x	x	x	x	x
Basic numeracy and communication	x	x	x	x	x	x	x	x	x	x
Basic data input and processing	x	x	x	x	x	x	x	x	x	x
Advanced literacy		x	x	x		x	x	x	x	x
Quantitative and statistical skills		x	x	x	x	x	x	x	x	x
Complex information processing		x	x	x		x	x	x	x	x
Appropriate linguistic skills	x	x	x	x	x	x	x	x	x	
Process analysis	x	x	x	x		x	x	x	x	x
Creativity			x	x		x		x	x	
Complex problem solving		x	x	x		x	x	x	x	x
Conflict resolution	x	x	x	x	x	x	x	x	x	
Problem management	x	x	x	x		x		x		x
Risk management	x	x	x	x		x	x	x		
Environmental awareness	x			x				x		
Energy efficiency				x				x		
Resource reuse/recycling	x			x				x		
Waste management (reduction and reuse)	x			x				x		
Product life cycle impact assessment		x		x		x	x	x		

Professionals
Science and engineering professionals
Food processing and related trades workers
Engineering professionals (excluding electrotechnology)
Professional Job profile: civil engineer
ESCO link: http://data.europa.eu/esco/occupation/d7d986e1-7333-431b-9719-0c5c6939e360
Alternative labels: director of infrastructure projects, civil engineering consultant, civil engineering expert, infrastructure project manager, investments civil engineer, quality assurance civil engineer, civil engineering specialist, harbour civil engineer, civil engineering adviser
Civil engineers design, plan, and develop technical and engineering specifications for infrastructure and construction projects. They apply engineering knowledge in a vast array of projects, from the construction of infrastructure for transportation, housing projects, and luxury buildings, to the construction of natural sites. They design plans that seek to optimize materials and integrate specifications and resource allocation within the time constraints.
ISCO number: 2142
Essential
knowledge
civil engineering
engineering principles
engineering processes
mining, construction and civil engineering machinery products
technical drawings
skill/competence
adjust engineering designs
approve engineering design
ensure compliance with safety legislation
perform scientific research
use technical drawing software
Optional
knowledge
construction products
contamination exposure regulations
renewable energy technologies
skill/competence
analyse environmental data
abide by regulations on banned materials
assess project resource needs
collect mapping data
develop efficiency plans for logistics operations
Future skills
Essential
adaptability & adapt to change
complex problem solving
continuous learning
critical thinking & decision making
advanced literacy
risk management
IoT
Big Data
BIM methodology
use of new measurement systems: drones
3D Printing
energy efficiency of buildings and infrastructure.
risk management related to climate change
sustainable waste management - Circular Economy
use of new measurement systems: drones
sustainable resource management
Optional
teaching and training the others
creativity
cybersecurity
quality procedures related to digital transformation

Figure 2. An example tab of the automated database generated for the job profiles related to the civil engineering industry.

Table 4. Near-future skills for each profile: Specific skills.

Specific Skills	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 6	Profile 7	Profile 8	Profile 9	Profile 10
Application of new technologies to civil engineering		x		x				x	x	x
Drones	x	x	x	x		x		x	x	x
BIM methodology				x				x	x	x
Robotic construction	x			x				x		
3D Printing		x	x	x		x		x	x	
3D laser scanning				x				x	x	x
Novel construction materials				x				x	x	
Quality procedures related to digital transformation			x	x			x	x		
Energy efficiency of buildings and infrastructure.				x				x	x	
Risk management related to climate change				x				x	x	
Sustainable waste management-Circular Economy	x			x				x		
Sustainable resource management	x			x				x	x	
Project management		x	x	x		x	x			
Ergonomics		x	x	x						

4. Training and Curricula Requirements

One of the key challenges of an effective curriculum design is maintaining the communication and cooperation between the different stakeholders and training centers in order to meet both educational and employer needs. Stakeholders have varied perspectives and attitudes and use different terminologies when dealing with the sector's knowledge, skills and competences. A common profile description template related to civil engineering that uses ESCO terminology and incorporates definition, tasks and skills needs, etc., will facilitate the development of efficient curricula serving as a bridge or communication tool between the stakeholders and training institutions [93]. Such a tool would significantly speed up the agreement on curricula design among the industry, trainers and policy-makers.

Once the skills needs are identified (our research has addressed this issue), the training providers and the human resources department of the construction companies will together decide which skills to be included in the curricula.

Therefore, and based on the research that we executed, we propose to introduce at least the following items in the civil engineering training plans, either as a new subject or as part of subjects that already exist:

- New measurement methodology and data acquisition
- BIM methodology
- Project management
- Sustainable resource management
- Circular economy: waste management in civil engineering
- Challenges of climate change in civil engineering: minimize impacts of works, efficiency of buildings and constructions, and more sustainable transport infrastructures and mobility plans

The described concepts are prevailing need for the sector, and they have been extended before the implementation of the new curricula for the new professionals of civil engineering. Hence, it is necessary to adapt the formation to the actual context. Their incorporation into training programs and curricula will prepare the workforce for the future challenges and allow them to develop successful professional careers in the civil engineering sector.

5. Conclusions

One of the major conditions for the civil engineering sector to recover from the impacts of the 2007–2008 global financial crisis and overcome the challenges coming up with digitalization, sustainability and environmental requirements is having a competent and multi-skilled workforce. Thus, the civil engineering sector is in need of further lines of investigation and new projects, especially the ones focusing on the skills needs related to the digital transformation and sustainable growth of the sector. Within this context, in this article, we present a definition of current and future profiles of the sector; the aim of the work is to be a guideline for a roadmap for the next generation of projects related to development of skills and competences in this subject.

The first step to achieve this workforce is to identify the current skills requirements, address the future skill needs and analyze the skills gaps. Only then would it be possible to prepare successful training programs and close this gap through upskilling and reskilling of the workforce.

In this work, we analyzed the current skills requirements and identified the near-future changes in the professional skills needs in the civil engineering sector. As detailed in Section 2, during the execution of our research, we benefited from taking part in many European projects related to the development of skills and competences associated with engineering, which we used to complement our desk research. As a result, and combining it with a current abstraction of the ESCO database, we created an automated database for the current and future skills requirements for the civil engineering sector job profiles. It is our belief that it can serve the sector as a fundamental framework through all the midterm-future industrial changes. Due to our collaboration with ESCO experts, the results of this research will contribute to the continuous improvement of ESCO, and they are compatible with the ESCO structure, which is a fundamental tool for the European job market, education and training. We also believe that this work can be used as a guideline by trainers, sectoral leaders and policy-makers to develop the most convenient training programs. We can bridge the skills gaps between the workforce and the sector demands only through efficient training programs. Regarding the future workforce, the construction industry can win over new talents with desired qualifications only through delivering specific training and education related to the sector. Thus, many of the lacunae in the education of civil engineering are already on their way to be filled. Regarding the current workforce, continuous training programs aligned to the new future skills needed will transform workforce towards updated qualifications. As a consequence, the sector will keep up with industrial transformation and global competitiveness. Therefore, well-developed continuous training and education programs are crucial for the sector.

Further research of this project will be oriented to the design and implementation of a roadmap for the development of the skills needed in the sector considering both students and current workforce.

Supplementary Materials: The following are available at http://www.mdpi.com/2076-3417/10/20/7226/s1, Figure S1: an example tab of the automated database created for the job profiles in the civil engineering industry.

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Abbreviations

The following abbreviations are used in this manuscript:

GDP	Gross Domestic Product
BIM	Building Information Modeling
SME	Small and Medium-sized Enterprises
ESCO	European Skills, Competences, Qualifications and Occupations
ISCO	International Standard Classification of Occupations
ILO	International Labor Organization
VBA	Visual Basic for Applications
ICT	Information and Communications Technology
VR	Virtual Reality
AR	Augmented Reality
IoT	Internet of Things
STCR	Single task construction robots
GPS	Global Positioning System
ATL	Autonomous Track Loader
ESSA	Blueprint "New Skills Agenda Steel": Industry-driven sustainable European Steel Skills Agenda and Strategy
DRIVES	Development and Research on Innovative Vocational Educational Skills
APPRENTICESHIPQ	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
SMEs	Small and Medium Enterprise
CEPIS	Council of European Professional Informatics Societies
CEN	European Committee for Standardization
EUCEET	European Civil Engineering Education and Training

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