Shaping the Future of Construction Professionals

Marzia Bolpagni, Rui Gavina, Diogo Ribeiro, and Ignasi Pérez Arnal

Abstract Emerging technologies and methodologies are changing the way we work and live. The Fourth Industrial Revolution, also called Industry 4.0, has a direct impact on how we communicate and interact with others. All industries are facing this transition including the built environment that is moving to "Construction 4.0" era. Climate change and global health emergency have accelerated the digitization and automation of construction sector showing the relevance of having trusted real-time information to support decision-making processes. Construction 4.0 is bringing new job opportunities, and new knowledge and skills are required. This chapter discusses what is Industry 4.0 and how it is disrupting the built environment, showing how existing professions are evolving and which new ones are emerging. The role of educational institutions is presented to underline the importance they have in shaping the future of construction professionals. The required knowledge and skills are discussed, focusing not just on the hard ones (use of technologies, e.g. big data, cloud computing, blockchain) but also on soft ones (such as digital leadership and digital communication). Finally, the chapter introduces the topics that are presented in detail in the book to guide the readers in focusing on the aspects that might be more relevant for their professional growth.

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1 Industry 4.0

Industrialization is referred as a succession of historical eras of adoption of technological clusters and organizational innovations, which combined enabled extensive development at various aspects such as industrial productivity, goods and incomes. These eras, or periods of transition, are known as Industrial Revolutions and share common features, defining them as revolutions, instead of simple evolutional changes in industry. The accumulation of a sufficient volume of new technologies of industrial production, leading to the emergence of new economic systems, stands as a key requirement to recognize the advent of an Industrial Revolution. When these technologies reach some threshold number and are ready for practical application into various production systems, the transition process starts [1]. The wide spectrum of sectors influenced and changed during these revolutions is another precondition for an Industrial Revolution. In fact, although industrialization is propelled by innovations, those are not only technical, but also institutional, inducing economic, social, organizational, legal and ethical changes, which ultimately transforms the whole society [2].

Historically, there are four distinct Industrial Revolutions formed from the seventeenth century to present. During these revolutions, various technologies, concepts and approaches have emerged (Fig. 1).

The First Industrial Revolution relates to the invention of the steam engine in the seventeenth century, but the transition from manufacturers to factories and from manual labour to machine labour began in the late eighteenth century. The Industrial Revolution influenced not only the development of science and technology, but also the change of the structure of society, urbanization and emergence of new specialties [3]. The industrialization required new infrastructures for industrial equipment and transportation for logistics, thus the relevance of steam engines and cast-iron products.

The Second Industrial Revolution relates to electrical energy (with the inventions from Nikola Tesla and Thomas Edison) and mass production (with the assembly lines from Henry Ford) in the late nineteenth century. Despite all the previous inventions and technologies, it was not before this period that technological developments and innovations had a scientific-based approach [4]. The accumulated knowledge provided guidance on how to make technology more efficient, marking this era with revolutionary innovations (Fig. 1). Another important aspect is the change in nature of the organization of production. The Second Industrial Revolution witnessed the growth in some industries of economies of scale. Large corporations were created and, with that, the development of assembly lines and the rise of technological systems, as roads and railroads, telegraph networks, power lines, telephone lines, water supply and sewer system, that

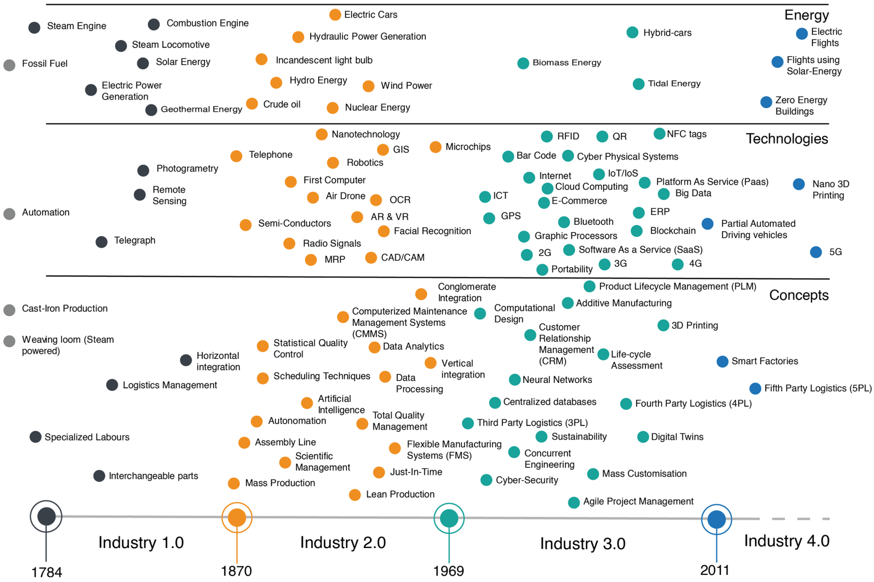

Fig. 1 Industrial Revolution Innovations timeline (the figure is not precise nor comprehensive, but it aims to provide an overview of developments over time)

needed to be coordinated to respond to a consumer-based society. The Second Industrial Revolution has yet to be fully experienced by 17% of the world as nearly 1.3 billion people still lack access to electricity [5].

The Third Industrial Revolution, dated to the late twentieth century and for most industries still undergoing, relates to the implementation of computers in production, automatization, electronics, the Internet and renewable energies. It is usually labelled as the computer or digital revolution because it was catalysed by the development of semiconductors, mainframe computing (1960s), personal computing (1970s and 80s) and the Internet (1990s) [5]. The rise of digital tools and equipment enables the collaboration on designs over time and distances and provides avenues for direct digital manufacturing. By sending files directly to machines, this technology provides manufacturing resources that are larger in scale than what any single manufacturer could afford. The Third Industrial Revolution is not yet widespread, as more than half of the world's population, 4 billion people, most of whom live in the developing world, are lacking Internet access [5].

The Fourth Industrial Revolution is used interchangeably with the term "Industry 4.0" to represent a disruptive innovation era, where the organizations and processes are connected based on technology and devices, autonomously communicating with each other across the whole value chain. For the first time, an Industrial Revolution is predicted instead of observed. In fact, it is a recent and still undergoing transition, with a varying degree of adoption, being mostly observed in innovation-driven industries such as automotive, aerospace, and food and beverage [6]. Surprisingly, the adaptation to this revolution in other industry is rapidly growing, including the construction industry, observing exponential growth on research and development in this field throughout the past few years. This was incentivized by ambitious initiatives which proven a wide acceptance towards Industry 4.0 concepts (as shown in Table 1).

The term Industry 4.0 became publicly known at the Hannover Messe in 2011 when Professor Wolfgang Wahlster, Director and CEO of the German Research Center for Artificial Intelligence, addressed the opening ceremony. Industry 4.0 was promoted as an approach to strengthen the competitiveness, safety and transparency of the German manufacturing industry. The German Federal Government supported the "Industrie 4.0 Working Group" and integrated this project in its "High-Tech Strategy 2020 for Germany" initiative. The first recommendations for implementation were published in April 2013 [7] and described the vision, basic technologies, the aims and scenarios for the implementation of Industry 4.0, but failed to provide a clear definition.

Since the concept is quite novel, there is still no consensus on a common definition for Industry 4.0. It is often used as a broad, generic and inclusive term to describe the confluence of trends and technologies that have the potential to reshape the value delivery mechanisms for services and products. Thus, some authors have pointed out the necessity of a dynamic and comprehensive definition, describing Industry 4.0 as a "*shift in the manufacturing logic towards an increasingly decentralized, self-regulating approach of value creation, enabled by concepts and technologies such as Cyber-Physical Systems (CPS), Internet of Things (IoT), Internet of Services (IoS), cloud computing, additive manufacturing and smart factories*" [8].

Hermann et al. [7] described Industry 4.0 term as a collection of technologies and concepts that aims at enhancing the whole value chain [7]. Within modular structured smart factories, the physical and digital environments communicate and collaborate over the Internet of things (IoT) in real time, creating cyber-physical

Table 1 Summary of some global and national initiatives towards Industry 4.0

Initiative name	Year	Location
Advanced Manufacturing Partner (AMP)	2011	USA
Industrie 4.0	2012	Germany
La Nouvelle France Industrielle	2013	France
Future of Manufacturing	2013	UK
Factories of the Future	2014	European Union
Innovation in Manufacturing 3.0	2014	South Korea
Made in China 2025	2015	China
RIE2020 Plan	2016	Singapore
Connected Industry	2017	Japan
Industry 4.0 test laboratories	2017	Australia
Next Generation EU	2020	European Union

systems (CPSs) and enabling a decentralized decision-making process. Internal and cross-organizational services are also integrated and connected, bringing greater flexibility to the production process and changing business models. Products can become services, through what is called the Internet of Services (IoS).

Industry 4.0 is associated with a significant number of developing technologies, but unlike the Third Industrial Revolution, it focuses on the improvement, integration and adaptation to existing technologies and equipment, transforming the supply chain (Fig. 2).

The underlying logic of this supply chain transformation is characterized by: (1) horizontal integration through networks via value chains, (2) vertical integration and networked manufacturing or service systems and (3) end-to-end engineering of the overall value chain [10]:

(1) **Horizontal Integration**
It incorporates the value interfaces between internal operations and between organizations, starting from suppliers to final customers in the same level of supply chain and within the same industry. The used information technologies vary from real-time track and trace services to integrated production planning and control systems. The horizontal integration improves product life cycle using integrated information systems (interrelated components working together to collect, process, store and disseminate information to support decision-making, coordination, control, analysis and visualization in an organization).

(2) **Vertical Integration**
It is comprised of intelligent cross-linking and digitalization of business units in different hierarchal levels within the organization. Therefore, vertical integration enables flexible transformation to smart factory and provides the production of small batches and more standardized products and processes. For instance, smart machines create a self-automated ecosystem that can be dynamically coordinated to affect the production of different product types,

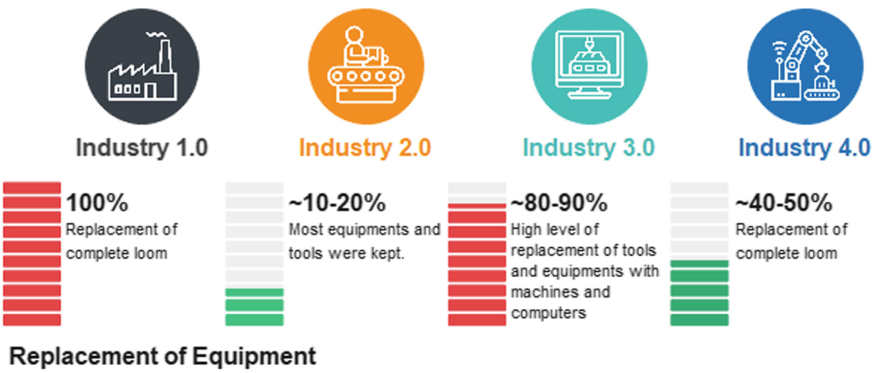

Fig. 2 Percentage of equipment replacement from Industry 1.0 to Industry 4.0 (adapted from [9])

associated with the generation for big data to be processed to operate the manufacturing processes more efficiently.

(3) **End-to-End Engineering**
It provides products and processes through digital integration. End-to-End Engineering comprises sensors or communication devices for data collection, which empower data analytics tools, as well as the creation of new digitized products, that enables the creation of cyber-physical systems. By integrating new methods of data collection and analysis, stakeholders would be able to take evidence-based decisions on resources allocation and product use and query their processes to meet the customer value.

Since it was first coined in 2011, Industry 4.0 has been focusing on the use of integrated technologies for improved efficiency and increased flexibility in the production of goods. Its role on the social, societal and environmental landscape was not in the forefront of this revolution, and therefore, the concept of Industry 5.0 recently emerged [11]. Industry 5.0 is not to be seen as a progression of Industry 4.0, but as a complement to address the aforementioned. The fundamental components of this concept are: (1) human-centric approach; (2) sustainability; and (3) resiliency [11]:

(1) **Human-Centric Approach**
The human need and interest must be in the core of the production process. Technology usage and the production process should be adapted to the workers' needs, and technologies should not infringe fundamental rights, such as privacy, autonomy and human dignity.

(2) **Sustainability**
Reuse, repurpose, recycle and reduce must be key principles for the industries to develop circular processes. Technology should be used to optimize resource efficiency, minimize waste and reduce energy consumption and greenhouse emissions.

(3) **Resiliency**
Industrial production should be adaptable and accommodate times of crises, such as geopolitical shifts and natural calamities. Resilient strategic value chains, adaptable production and flexible business processes should be developed, to cope with these unstable periods.

The authors considered the combination of Industry 4.0 and Industry 5.0 principles in their vision for Construction 4.0.

2 Construction 4.0

Innovation and technology have been crucial to the development of the construction industry. Despite being described as traditional and late adopter of new technologies, all Industrial Revolutions had a profound impact in construction sector.

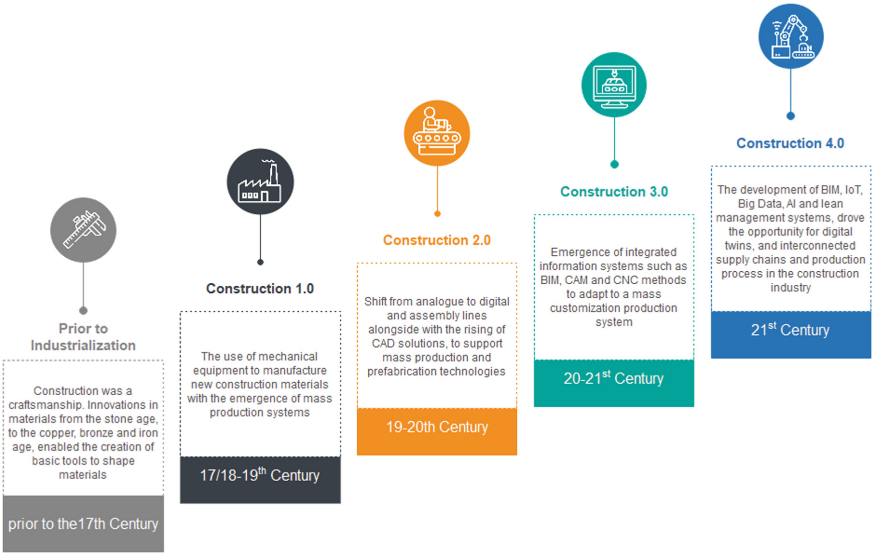

Fig. 3 Timeline for the successive development of the construction industry

The correlation between each period of industrialization with the construction industry is illustrated in Fig. 3.

Innovation and technological development have been crucial to the development of the construction industry. Evidence goes back to the Copper and Bronze Age (5000 BC–1200 BC), when metal could be used for tools that enabled early builders to start shaping materials.

During the First Industrial Revolution, the mechanical heavy industry experienced exponential growth leading to the creation of new building materials. This included glass and cast iron, being used by engineers and architects to create unparalleled and unimaginable buildings at that time, in terms of form, frame and functionality [12].

The Second Industrial Revolution was considered as an innovation-based era supported by emerged technologies through scientific approaches. That drove the industry with cost-effective and cost-efficient mass production of steel and masonry materials for energy power plants, telephone networks, lifts and railroad infrastructure. This revolution conducted the construction industry in terms of innovation in architectural design through the rising of computer-aided design (CAD) as a solution to deliver design intent to production sites that emerged more vertical construction and prefabrication technology [13].

The Third Industrial Revolution has connected technology to architecture and engineering. The emergence of internet, information technology (IT), and the availability of personal computers, led to a shift from analogue to digital construction and from mass production to mass customization. Digital architecture and engineering expanded the limits of creations and analysis using 3D CAD software and later combining it with building information modelling (BIM), which enabled greater efficiency and precision in design products. Fabrication in some industry segments became closely connected with 3D CAD models and computer-aided manufacturing (CAM), using computer numerically controlled (CNC) fabrication processes. These facilitated mass customization and computerized production of building elements, making complex construction more economical and feasible [13].

With the advent of the Fourth Industrial Revolution, the construction industry is facing the opportunity to benefit from the availability of digital data and online digital access, to interconnect information between the physical and digital realms. This evolution from digitization to digitalization, i.e. using digital information and technologies to transform the business models, enables transitioning the current reactive practice to a predictive practice. The combination of BIM with Industry 4.0-related technologies that will be covered in this book, such as IoT, cloud computing and artificial intelligence, robotics, blockchain among others, is taking the construction industry to a new era, commonly labelled as Construction 4.0.

Construction 4.0 definition has dynamically evolved during these past years [8]. The link between Industry 4.0 and construction was first mentioned in an article back in 2014, related to automated 3D-printed prototypes and its value for the customer. In 2015, an article describing specific automated process that monitors the construction of dams mentioned the term “Dam construction 4.0”. However, the first mention and characterization of Construction 4.0 as a global concept was made by the German consultancy Roland Berger, in their report “*Digitization in the construction industry: Building Europe’s road to “Construction 4.0”*” [14]. This concept was primarily based on the potential of digitization in the world of construction and identified four key areas: digital data, automation, connectivity and digital access.

Being a recent term, Construction 4.0 definition has dynamically evolved during the past years [8] and there is no widely accepted definition. Sawhney et al. [15] define Construction 4.0 as a “transformative framework” represented by a confluence of three main trends: (1) industrial production and construction, (2) cyber-physical systems and (3) digital technologies:

(1) **Industrial Production and Construction**
The industrialized process of construction that goes beyond offsite production and advanced manufacturing in controlled environments. It includes 3D printing, prefabrication, modularization, robotics and the transformation of business models by redefining the strategic approach for the construction sector.

(2) **Cyber-Physical Systems**
The synchronous integration between the physical and the digital process, with the use of sensors and IoT to acquire important information from the physical layer and actuators to convert digital signals into physical actions.

(3) **Digital Technologies**
The digital ecosystem, under the concepts of BIM and cloud-based shared information. It encompasses the technologies that enable the creation and use of digital information, following a set of data standards and interoperability. These technologies enable reality capture, computational design, data acquisition, data analytics, artificial intelligence, simulation and analysis, virtualization and cybersecurity.

The convergence of these transformative trends comprises a plethora of technologies to enable the digitization, automation and integration of the construction process at all stages of the construction value chain. However, technologies are not the sole drivers of this transition. The authors believe that the key elements that contributes to an effective implementation of Construction 4.0 can be structured in three high-level clusters (Fig. 4): (1) technologies, (2) concepts and methodologies and (3) soft skills.

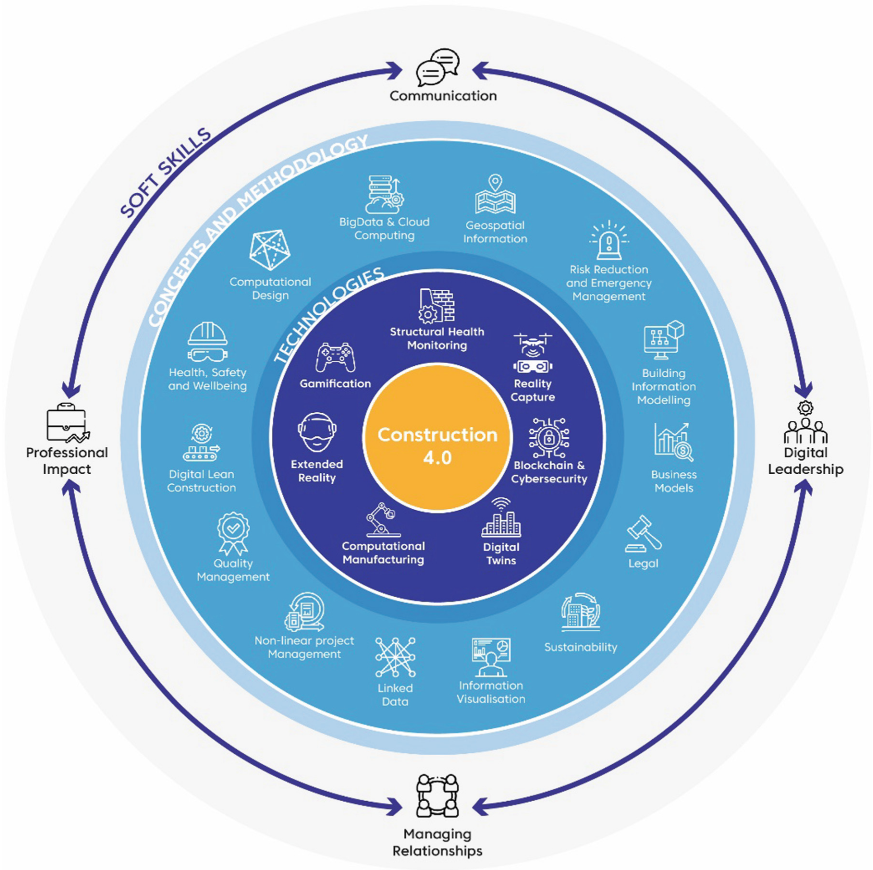

Fig. 4 Construction 4.0 main clusters

Concerning the technological cluster, cyber-physical systems (CPSs) and digital twins plays a pivotal role in Construction 4.0, representing the connection between the physical and virtual ecosystems, through Internet of things (IoT) and sensors, that provide the connectivity. Having a supportive role, reality capture enables digital monitoring processes (used for structural health monitoring, risk reduction and emergency management and health safety and well-being, among others) and digital representation of the built environment (used in digital twins, gamification, extended reality and BIM, among others). The digital to physical connectivity, over the IoT, sensors and cloud solutions, arises important concerns and challenges in cybersecurity and in current legal frameworks. One of the key technologies to enable digital information security, but also to improve efficiency, accuracy, trust and transparency in transactions with smart contracts is blockchain.

Regarding the concepts and methodology cluster, BIM is fundamental in the process of design and collaborative production and management of digital information related to the construction sector, creating the foundations for all information usage (for sustainability, health, safety and well-being and also risk reduction and emergency management, among others). BIM is also interconnected with the technological fields mentioned before and with data analytics and respective supportive fields of knowledge, such as linked data, information visualization, artificial intelligence (AI), big data and could computing, which are crucial for decentralized and data-driven decision-making. Construction 4.0 and the increasing industrialization in the architecture, engineering construction and operation (AECO) industry also bring the necessity to rethink business models and to adopt and adapt to this digitalized sector the prevalent project management methodologies of other industrialized industries (lean, nonlinear project management and quality management). To achieve the principles of flexibility and adaptation of Industry 4.0, computational design provides means to efficiently design and adapt solutions to new or changing requirements and establishing the connection with the production and construction process. Other principles, such as traceability and interconnected data between locations, suppliers, companies and assets, are supported by Geographic Information System (GIS) integrated with IoT. For a seamless integration of these concepts and methodologies with the supportive technologies, a set of appropriated regulations and policies needs to be set in place, requiring a revision of the legal framework.

The soft skills cluster relates to the vast variety of stakeholders involved in this complex industry, who ultimately are the key drivers to embrace any transition. Resistance to change, poor communication, lack of relationship skills and inadequate leadership are still among the main obstacles for digital transition and are becoming more relevant and prominent with the fast pace changing industry. More than technical skills, the capacity to learn, change, adapt and evolve is becoming more relevant for current and future professionals as they need to cope with the principles of adaptation and flexibility. Construction 4.0 is surpassing automation of tasks and entering the automation of decision-making processes, with the likes of AI, and therefore, the focus and need start turning to creativity and problem-solving skills.

The identified technologies, concepts and methodologies and soft skills can also be aggregated in five layers (Fig. 5): (a1) physical; (a2) digital; (a3) connectivity; (b) supported fields; and (c) enablers.

In the proposed framework, Construction 4.0 is centred on the interrelationships between physical (a1) and digital (a2) systems, which interact through connectivity (a3) systems, creating a cyber-physical environment. These interconnected layers are at the core of the proposed framework and support industry practices and activities, namely the ones identified in the supported fields (b). These were selected based on the criteria of being the ones more aligned and influenced by Industry 4.0 and Industry 5.0 principles. The intricate connections and dependencies of this framework with the inclusion of multiple digital technologies bring added complexity to this industry. With that, a set of fields to ensure it is manageable, secure, trustful, efficient and adoptable is required. Those fields are represented in the enablers layer (c).

The physical layer (a1) is comprised by construction assets, construction sites, robotics, industrialized production, equipment, machinery and people. It relates to the real-world components and resources involved in the activities performed throughout all stages of the building life cycle that can be connected to a digital environment, to enable automated decision-making processes, decentralization and adaptation based on data gathering and analytics.

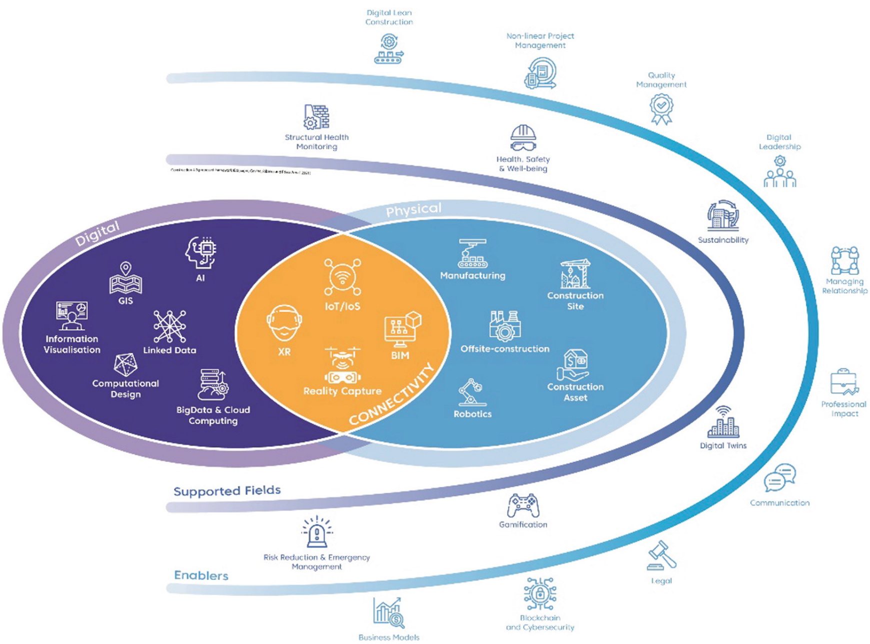

Fig. 5 Construction 4.0 proposed framework

The digital layer (a2) includes the concepts, methodologies and technologies that create, transform, analyse and present digital information. This information will be linked through the connectivity fields to the physical environment. This layer includes big data and cloud computing, AI, linked data, information visualization, computational design and GIS.

BIM, reality capture, IoT and extended reality (XR) lie within the connectivity layer (a3). The sense of connectivity in this framework transcends the conversion of digital signals into physical actions, through what is called actuators in a cyber-physical system (CPS). It also includes digital information gathering and monitoring from the physical environment with reality capture, the interaction between physical and digital worlds with extended reality and BIM, as the key methodology for digital information management, including the establishment of digital information requirements, classification systems and production, collaboration and management methods and procedures. In this layer, IoT remains as one of the key drivers for information gathering and connectivity with the physical layer.

The supported fields layer (b) consists of industry segments or fields of study that are enhanced by the cyber-physical connectivity and data analytics from the information gathered. This allows data-driven decision-making processes and real-time monitoring enabling timely actions and predictions, for structural health, risk reduction and emergency management, health, safety and well-being as well as sustainability. Included in this layer is also digital twins, which is the conceptual result of the physical to digital integration and gamification that typically uses both digital information models and extended reality for training in various fields, such as health and safety.

As mentioned before, the challenges and complexity brought with Construction 4.0 require changes in management, social skills, policies and economic models. These are identified in the enablers layer (c). Existing advanced project management concepts in other industries, namely lean, nonlinear project management and quality management, need to be adopted in the AECO industry and adapted for the digital transformation process. Due to the challenges in Cybersecurity, the use of robotics and increase of linked digital information usage, it is needed to perform legal revision of contracts, changes of Business Models and adoption of technologies like Blockchain. Finally, the area worth stressing and often forgotten in the transition to Construction 4.0, which is also included in the enablers layer, is soft skills. Soft skills have the potential to unlock the full potentials of Construction 4.0 and change attitude of individuals and culture in organizations that are currently the main barriers towards an effective adoption.

3 The Role of Academia in the Training of Future Professionals

One key aspect to move towards Construction 4.0 is to have professionals who understand the key components and are able to apply in practice. To obtain these 4.0 professionals is fundamental to focus in two complementary fields: the existing professionals that need to be transformed and the students that have to be shaped in terms of academic competencies. In both situations, the educational institutions play a key role.

In recent years, several reputed worldwide organizations proposed specific curriculum guidelines for the training of the future professionals of Industry 4.0. The most relevant contributions have been published by OECD [16], United Nations [17], UNESCO, through the International Bureau of Education (IBE) [18, 19], and European Commission [20].

All the proposals of curriculum guidelines were developed based on a common base of general orientations. First, the guidelines are driven and supported by a collaborative work of the key stakeholders, namely higher education institutions, industry and students. The guidelines intend to promote the efficiency, allowing for the optimal use of time, effort and cost, as well as being applicable in different cultural and geographical environments in a context of global cooperation. In terms of time schedule, the guidelines implementation may require a period of 15–20 years for educating/upskilling the professionals of Industry 4.0, particularly in case of highly complex technologies [20]. Also, the guidelines should be flexible enough to survive to changes of scope and timescales, and therefore should allow continuous adjustments and revisions. Finally, the guidelines intend to develop customized flexible curricula framework instead of offering rigid solutions.

A framework proposal for Curriculum Guidelines 4.0 consists of the following eight distinctive but interconnected elements presented in Fig. 6 [20]: (1) strategy, (2) collaboration, (3) content, (4) learning environment, (5) delivery mechanisms, (6) assessment, (7) recognition and (8) quality. Each aspect will be summarized below, and it can be used as a reference to create bespoke educational and training programmes.

Strategy (1) is focused on the conceptual aspects of the educational offer, particularly, assessing learner's needs, developing curriculum goals and intended learning outcomes. The main conceptual principles for strategy are focused on [20]:

- Preparing students for lifelong learning: Experts predict that professionals will have to go back to school at different stages of their career and develop deep expertise in new domains. The T-career model (when students go to university in their early twenties and learn on the job for the rest of their life) will be replaced by the M-career model (when workers go back to study multiple times in a 40–50-year career) to stay updated.
- Offering a big picture education in which the educational offer fits the overall learning trajectory and labour market.

Fig. 6 Curriculum guidelines framework (adapted from [20])

- Considering the industry needs (employability), the societal needs (sustainability and ethics), as well as student's individual characteristics (i.e. respecting diversity of student's contexts and capacities).
- Shifting from knowledge towards competencies that students should acquire for their personal development and for employment and inclusion in a knowledge society, which involves adding to the curriculum a dimension of mindsets, e.g. growth, innovation, ethics and safety.
- Ensuring freedom of curriculum goals and learning outcomes from conventional qualification frameworks to offer relevant personalized learning.
- Viewing students as change agents and actively engaging them in curriculum development and implementation.

Collaboration (2) refers to connecting individuals and institutions by facilitating the exchange of practices and resources with a view to improve the educational offer. The main conceptual principles for collaboration are based on [20]:

- Further increasing university–industry and university–university collaboration in terms of both volume and diversity of collaboration forms (e.g. internships, mentoring, project banks, think tank competitions, summer schools, etc.).

- Acknowledging the role of industry partners as educational, research and employment partners, and ensuring their engagement in the full student's learning experience, including strategy development.
- Creating more opportunities for exchanging experiences with other educational institutions (e.g. via joint platforms, thematic networks, etc.).
- Facilitating peer-to-peer learning, to enable students to learn with and from each other as fellow learners, which can be facilitated using collaboration tools and platforms.
- Creating effective learning ecosystems that manage all key stakeholder groups, including education and training providers, industry, policy-makers, supporting structures and broader community.
- Shifting from human–machine interaction to human–machine collaboration as an evolving collaboration form.

The **content** (3) dimension refers to the nature of educational content and includes specific conceptual principles related to the syllabus. Education and training providers need to teach the curriculum of the future, not the past. The main conceptual principles for content are the following [17]:

- Upgrading the technical side of the curriculum to accommodate the learning of next-generation robotics, additive manufacturing, smart materials, artificial intelligence, IoT, predictive analytics, augmented and virtual reality, sensors, signal processing, etc. Those technical aspects will be covered in detail in the book with examples related to the construction sector. Knowledge in computer sciences will be essential as well as expertise and capabilities in data analytics, including control and manipulation of big and small data through algorithms, programs and scripts, cybersecurity, cloud computing and optimization techniques in design, engineering and research. Future professionals will therefore have to be data literate, i.e. have a good working knowledge of and skill in algorithmic thinking and programming, statistics, domain knowledge and data visualization techniques to operate successfully in an increasingly data-rich engineering environment [20].
- Incorporating non-technical disciplines into the curriculum (e.g. communication, project management, arts, marketing, etc.), to develop cross-cutting competencies and a mindset beyond technical expertise. In particular, the curricula of the new age need to stimulate creativity and innovation skills, "out-of-the-box" thinking, divergent thinking, opinion generating and subjective interpretations. The company's recruitment based on specific technical knowledge becomes less important than recruiting a person with great skills. Those "soft skills" are key as discussed in paragraph 2.
- Paying attention to questions of ethics, social inclusion, diversity and sustainability (e.g. incorporating the Sustainable Development Goals (SDGs) into the curriculum—Fig. 7). A course on ethical principles is a useful and potentially critical component to any curriculum aiming to prepare future professionals to be effective contributors to a sustainable society.

Fig. 7 United Nations Sustainable Development Goals (SDGs) (adapted from [21])

- Offering a holistic view of product and system life cycles, in which students learn to alternate between the abstract and the precisely detailed, to deconstruct big problems and accept failure, as well to model real-life situations by simplifying assumptions.
- Teaching students how to acquire knowledge from big data and how to find out what to make of it when it has been found. In future, Internet will form the main source of knowledge at the university. New media literacy and especially digital literacy will become key components of engineering education.
- Teaching students to be mindful of their safety and ergonomics at work, and specifically about the necessity of maintaining good physical and mental health, and the possible consequences of risk exposure.

Learning environment (4) includes types of environment that is created during the educational or training programme. The learning environment refers to both the qualities of the space (both physical and virtual) in which learning activities are situated, and other intangible aspects that support the social and emotional dimensions of learning. The main conceptual principles for learning environment are centred on [20]:

- Applying problem-based learning, i.e. stimulating students to work on challenging real-life problems for which there are no established solutions, encouraging students to contextualize their theoretical learning in relation to how it would be useful in the world around them.
- Instead of focus on standardized thinking, correct answers and objectivity of judgement, creating a learning environment that would stimulate creativity, forming of own opinion and divergent interpretations.
- Creating a culture that accepts potential failures and developing the ability in students to turn those failures into valuable learning experiences.

- Creating learning environments that can offer experiences relevant to real-world working conditions, in a physical or virtual form.
- Encouraging collaborative learning by offering suitable physical spaces and virtual platforms for diverse forms of collaboration, including collaboration with peers, industrial partners, community, etc.
- Stimulating technology-enabled learning, encouraging the use of technology and software applications for learning, including Massive Open Online Courses (MOOCs), mobile learning, gamification, augmented and virtual reality, artificial intelligence, etc.

Delivery mechanisms (5) refer to how learners experience and access education/training. They may include in-person learning, where teachers/trainers and learners interact face-to-face or technology-enabled learning, which includes e-learning and mobile learning, Massive Open Online Courses (MOOCs) and Small Private Online Courses (SPOCs), game-based learning, wearable electronics, embedded sensors in the learning environment and software-based learning, and immersive technologies like virtual and augmented reality. Additionally, a blended learning strategy, which consists in a combination of in-person and technology learning, can be adopted.

Assessment (6) refers to the several methods of evaluation and their relevance to different types of educational offerings. Common methods of assessment include the self-assessment (students evaluate their own work and progress towards the learning objectives), peer assessment (students evaluate each other) and institutional assessment (manual evaluation of students' responses in quizzes, interviews, assignments, presentations, practical examinations and other means of formal evaluation, or eventually digitized or automated modes of assessment).

Recognition (7) traditionally refers to the process of issuing and acknowledging accredited certification or titles that have formal value for mastery of skills or knowledge. Typically, this dimension focuses on the formal (institutional) recognition in the form of diploma and degree certification. However, in the scope of a lifelong learning strategy, recognition must expand to areas such as accreditation schemes for specific training and international certifications. Otherwise, an informal (social) recognition is sometimes adopted, which refers to the acknowledgement of knowledge, skills and competencies by peers or stakeholders who work with the individual.

Finally, **quality** (8) refers to the expectations derived from the educational process of students and employers. Students value outcomes that improve their employability or added value for their employer. Employers relate the quality of employees' professional training to the ability of having an efficient and quickly adaptation to the company's culture, as well as their contribute for the economic success of the company. The general framework for Curriculum Guidelines 4.0 can be adapted for the specificities of Construction 4.0. In fact, at the present time, there is still a lack of consolidated experience in the construction sector. However, in the forthcoming years, it is expectable that the results of real academia pilot projects may become available.

4 Emerging Professional Profiles

4.1 From Millennial Tradition to New Millennium Construction

A new series of roles and labour gaps are arising from the demands of Construction 4.0. There are evident gaps between professionals and methodologies, technicians and digital applications, employers and employees and skills. These discordances to adopt new techniques and methodologies are usually identified under the paradigm of "resistance to change" or "acceptance of the new technology". Learning sufficient skills demands time and effort and three key issues appear: the impact of the age of the labour force [22], the open-mindedness of people to adopt a change and the design plus the related documentation factor.

Historically, architects are used to sketch while engineers were used to calculate; now the first have to be proactive in generate deliverables, and the second have to be engaged to continuously interact with the design. Nevertheless, builders were following instructions and now they are required to be participating in initial processes and to design the construction processes too. Architects, engineers and builders were siloed—also clients, manufacturers, providers and installers—but now they are required to communicate, share and use a unique and common source of information enabled by the use of information models [22].

Anyway, it is difficult to identify the overall consequences of the use of an infomation model and to refer it to all data used during the entire construction project life cycle [22]. Inner transformation of the talent acquisition and hiring by skills instead of contracting by academic curricula is creating a very similar pathway between any professional—no more depending on the age or the experience. People who will be able to be resilient will be in the race of getting better jobs. In fact, the ability of getting new job positions will rely on two different but connected skills: hard skills and soft skills. The first one is related to tools and technology (hard skills) as drone piloting, laser scan dragging, robots follow-up, etc. And the second one is focused on intercommunication, coordination, the use of platforms to share information, promotion of collaboration, cooperation and appropriate use of human and ethical resources (soft skills). Meanwhile, it is still difficult to see academia introducing this approach for students in education curricula [11] (as presented in paragraph 3) and for professionals at continuous learning centres.

The question is how the reaction to this new emergent ecosystem will be assumed by each stakeholder. Will existing professionals and construction employees have to learn to adapt their actual processes (upskill) or will they have to abandon the usual methodologies and learn new ones (reskill)? Will they be able to include in their agenda the verb "unlearn", apply it to their practices and really change for new digital ones? Or due to the fact that they are not computer natives, this will not really be possible?

To embed these skills and knowledge competencies is necessary to envision three phases: strategy phase, management phase and operation phase.

Awareness of latest methodologies and technologies, new value proposition, industry challenges, and economic and environmental drivers are the essential topics to achieve in the first phase, the strategic one.

Interoperability and exchange standards, managing compliance, AI-BIM-Lean software and hardware, collaboration tools, software evaluation, selection and use are the basement for management and operation phases (and demolition that will be so important when the sector has to achieve circular construction and SDG—Sustainable Development Goals; see Fig. 7).

So, the gaps between traditional academia schemes and advanced syllabus are identified following the absence of key topics including [23]: blockchain technology, the Internet of things/sensors, advanced materials science, advanced data and analytics, augmented and virtual reality, advanced energy storage and creation, advanced offsite manufacture, artificial intelligence/automation of processes, robotics, 3D printing and additive manufacturing, drones and autonomous vehicles. The configuration of the own AECO sector creates the first crucial gap: to work in a market that contents so different scale companies, studios and factories. Small and medium enterprises (SME) [24] with less of 20 employees are the 95% of the European market and mean more than 43.6 million jobs and 3.1 million companies. Proactive adoption of new digitally based approaches will have to be interiorized in each one of these companies, and this will be essential to meet and serve the new clients' demands. Developing these gaps in educational programmes in conjunction with the IT industry is mandatory. IT industry offers more applications than the AECO sector is demanding. To cover existing knowledge gaps in knowing what means big data, data ownership and open and shared access is transcendental. AI design, prefabrication, robots, 3D printing and artificial intelligence are a new wave of systems that now are connected to voice recognition and to image recognition. It is extremely important to be open-minded: the educational gaps are not affecting only AECO sector but also the initiators of the process (owners and developers) and its finishers (specialist subcontractors and sub-subcontractors, manufacturers, distributors, installers, suppliers and providers) because new business models are appearing. Intelligent buildings and smart cities have already entered into widespread use, and they are changing the way the sector operates and interoperates [24].

4.2 Reskill and Upskill as Transformation of Human Capital

New emergent technologies and methodologies generate new emergent profiles. But are there available if they are destroying the basement of what they learnt? It is a difficult process to adapt and adopt new environments. Construction 4.0 not only is an evolution of the sector, but also pleads for its radical transformation as discussed in paragraph 1. Next-generation EU programmes and other funds in other countries such as USA and Asia are asking for the total reform of sectors, and their approval will exist if a "radical" transformation is assumed by AECO sector [25]. They advocate for three concepts: re-industrialization, digitization and sustainability. Three concepts directly bomb a sector that is recognized as a non-industrialized sector (only the production and manufacturing of its materials and products can be considered as factory-made, so under the usual lean management philosophy), and then, industrialized construction is strictly part of the new paradigm [26]. And, as mentioned before, AECO sector is in the queue of less digitized activities in the list of productive sectors and a sector that is the one that is the biggest consumer of energy, producing more CO_2 emissions, generating the biggest amount of solid waste and reusing its obsolete built assets in near-zero opportunities.

Thirty-nine differences were identified [27] only for BIM and traditional education, and it is possible to identify similar quantities of gaps for lean construction, integrated project delivery, artificial intelligence adapted to design and construction and maintenance processes. Thus, it is necessary for the reskilling of experienced professionals and upskilling for students and freshers that have not had any contact with Construction 4.0 knowledge and practice during their studies and jobs.

Re- and upskilling requirements are greater collaboration, contribution from and participation of industry with academia, probably based in a new frame accelerated by the use of new technology inside the own training. The demands from industry, for example, for BIM-ready graduates, are the capability of articulating the benefits of BIM, to be able to use the technology relevant to their discipline, to be aware of the challenges imposed by existing methodologies and to be capable of delivering change. The increasing awareness of BIM across industry will drive this demand exponentially, and the response from academia will be a challenge [28].

Very few universities and professional associations are collaboration cross-teaming-based. Examples are Stanford, Pennsylvania State University, University of Southern California, Technion [27], ESTP Paris, Aalto University, TUM, University of Cambridge, ETH Zurich and UCL. This leads to the fact that a more intense exchange between universities and professional learning centres would have to be enhanced. EduBIM in France and esFAB in Spain are interesting initiatives to create a knowledge exchange platform on the one hand, and also, the Red BIM de Gobiernos Latinoamericanos at high public body level is breaking a wall on the other hand. But there is a shortage of implementation of transformational leadership, something that is critical for the success of the information management frameworks and nation-scale digital twin [29].

Anyway, a sector composed by small and medium companies [15] that do not know how industrial production as a construction process, Cyber-Physical Systems as new operational wisdom and digitization, will have to accelerate the watch to force laggards and un-knowers to integrate key methodologies such as BIM, Lean and Integrated Design and Project Delivery as a new relationship between stakeholders [30] in their works and worksites. And this is a decision that C's level has to achieve: to start to understand the value of data will be crucial in order to avoid the struggle to quantify its benefits as a narrative across their organization [29].

Skills and knowledge gaps will force the death of a number of companies [31] but at the same time are creating a set of new necessary professionals and roles. More employers need to invest in developing higher level of skills in the construction industry and need to explore the capabilities required to meet the demands created by re-adaptation of existing and emerging technologies in construction. The focus has to be on innovative modern methods of construction (MMC) [32], the ones that have been typified as modular, offsite and prefab construction. And this opens a new call to action based in upskilling existing workforce and organizations that must be funded and enabled strategically, including the encouragement of SMEs.

4.3 New Skills and Professionals in Construction 4.0

A new generation of workers will appear. There will be workers that instead of "building" will assemble elements [32], and this is affecting the relationship between products with the materials and building systems involved in erecting buildings and laying infrastructures. This is why Construction 4.0 enables the mid- and long-term creation of new 4.0 professionals related to unexpected fields such as supply chains, logistics, assembly, location intelligence and AI design. And therefore, the innovative capabilities to e-plan, e-budget, e-organize and even e-redesign the construction systems for their assembly lead to a high and new level of responsibility [33] throughout this new construction or manufacturing process derived of the new culture that appears with the culture of no necessary drawings, paperless projects and mobile communication.

Nevertheless, this situation offers a big opportunity for the construction sector [34], but also a huge challenge for existing companies. To change the equilibrium, it is essential not only to create new syllabus for learning courses at grades and postgraduate universities but to create new roles, new profiles and new jobs. Some of them are already recognized and even certified. For example, in relation to BIM, in the industry it is possible to find new job titles, some of them just added "BIM" or "VDC" to traditional roles: BIM/VDC Manager, BIM Coordinator, BIM Specialist, Information Manager and CDE Manager, Building Change Agents, Process Modeller, BIM Model Manager, BIM Architect, BIM Engineer, BIM Analyst, BIM Implanter, VDC Engineer, Design Strategist, BIM Applications Manager, BIM Job Captain, Interoperability Programmer. This trend shows an attempt to differentiate traditional professionals from the ones who understand and are capable to manage a digital environment.

Additional emerging roles have also been established in the UK in relation to the National Digital Twin programme including the Benefits Manager, Otologist, Data Regulator, Data Consumer, Data Lead, Data Producer, Data Steward, User Researcher and Data Governance Specialist [29, 35].

Despite the variety of names, the communality is that the majority of those roles required high soft skills including collaboration, adaptability, communication and leadership. In addition, all those roles required at least a basic understanding of programming language, security and ethics principles and data analytics.

It is also essential to have basic knowledge on concepts that support the Sustainable Development Goals such as resilience, CO_2 accounting and circular.

As a summary, the main new skills for Construction 4.0 are:

- Knowledge of BIM methodology and technology, as once upon a time it was CAD.
- Expertise in collaborative and agile working (e.g. lean construction as adoption of lean management principles).
- Knowledge of programming languages, data analytics and data visualization.
- Soft skills.
- Expertise to control the manufacturing and assembly processes (more related to logistics, stocking, transportation) on the one hand and planning, measurement and cost control on the other hand (production process engineering).

And, therefore, actual and new services will boost:

- Companies specialized in manufacturing and assembly processes.
- Companies specializing in sustainability including energy optimization and carbon emissions).
- Companies specializing in secure and ethical use of data.

5 How Different Chapters Can Help Current Professionals

As illustrated in the previous paragraphs, to be capable of working in Industry 4.0, diverse knowledge and skills should be acquired. Several articles and books cover the hard skills (e.g. use of technology), but it is rare to find a comprehensive reference that includes also the behavioural aspects. This book would like to fill the current gap and introduce key topics of Construction 4.0 that the reader can then further investigate using the references provided in each chapter.

Topics related to Construction 4.0 often have multiple facets, and they can belong to multiple categories; thus, the demarcation line is not sharply drawn. However, for simplification, topics have been divided into three categories:

- Concepts and methodologies.
- Technologies.
- Trends in soft skills.

Concepts and methodologies includes aspects that are mainly related to process innovation that can be supported by emerging technologies. Those aspects include: building information modelling (BIM) (Chapter "Building Information Modelling and Information Management"), computational design (Chapters "Introduction to

Computational Design: Subsets, Challenges in Practice and Emerging Roles" and "Advanced Applications in Computational Design"), artificial intelligence and machine learning (Chapter "Artificial Intelligence for the Built Environment"), big data and cloud computing (Chapter "Big Data and Cloud Computing for the Built Environment"), knowledge graphs and linked data (Chapter "Knowledge Graphs and Linked Data for the Built Environment"), data and information visualization (Chapter "Information Visualization for the Construction Industry"), lean construction (Chapter "At The Role of Lean in Digital Construction"), agile management (Chapter "Nonlinear Project Management: Agile, Scrum and Kanban for the Construction Industry"), sustainability (Chapter "Achieving Sustainability in Construction Through Digitally Informed Decisions"), Geographic Information System (GIS) (Chapter "Multi-Disciplinary Use of Three-Dimensional Geospatial Information"), business models (Chapter "New Business Models for Industrialized Construction"), risk management (Chapter "Smart Disaster Risk Reduction and Emergency Management in the Built Environment"), quality management (Chapter "Quality Management for the Built Environment"), health and safety (Chapter "Emerging Technologies for Health, Safety and Well-being in Construction Industry") and legal implications (Chapter "Legal Implications of Digitization in the Construction Industry").

Technologies includes the following emerging technologies: reality capture such as digital twins and Internet of things (IoT) (Chapter "The Role of Digital Twins and Their Application for the Built Environment"), laser scanning and drones (Chapter "Reality Capture: Photography, Videos, Laser Scanning and Drones"), extended reality such as virtual and augmented reality (Chapter "From Building Information Modeling to Extended Reality"), use of gaming for educational and training purposes (Chapter "Gamification for Visualization Applications in the Construction Industry"), advanced manufacturing and robotics (Chapter "Cyber-Physical Construction and Computational Manufacturing"), sensors for structural health monitoring (Chapter "Using Emergent Technologies on the Structural Health Monitoring and Control of Critical Infrastructures") and blockchain and cybersecurity (Chapter "Blockchain Opportunities and Issues in the Built Environment: Perspectives on Trust, Transparency and Cybersecurity").

Trends in soft skills includes essential behavioural aspects: leadership (Chapter "Digital Leadership for the Built Environment"), communication (Chapter "Communicating in the Construction Industry"), professional impact such as emotional intelligence and critical thinking (Chapter "Professional Impact in the Construction Industry") and managing professional relationships such as teamworking and remote working (Chapter "Managing Relationships in the Construction Industry").

Figure 8 provides a guide for current professionals to select aspects that are essential or highly relevant for their professional growth. Although the reader can just focus on few topics, we advise to read the entire book as all topics contribute to the successful implementation of Construction 4.0.

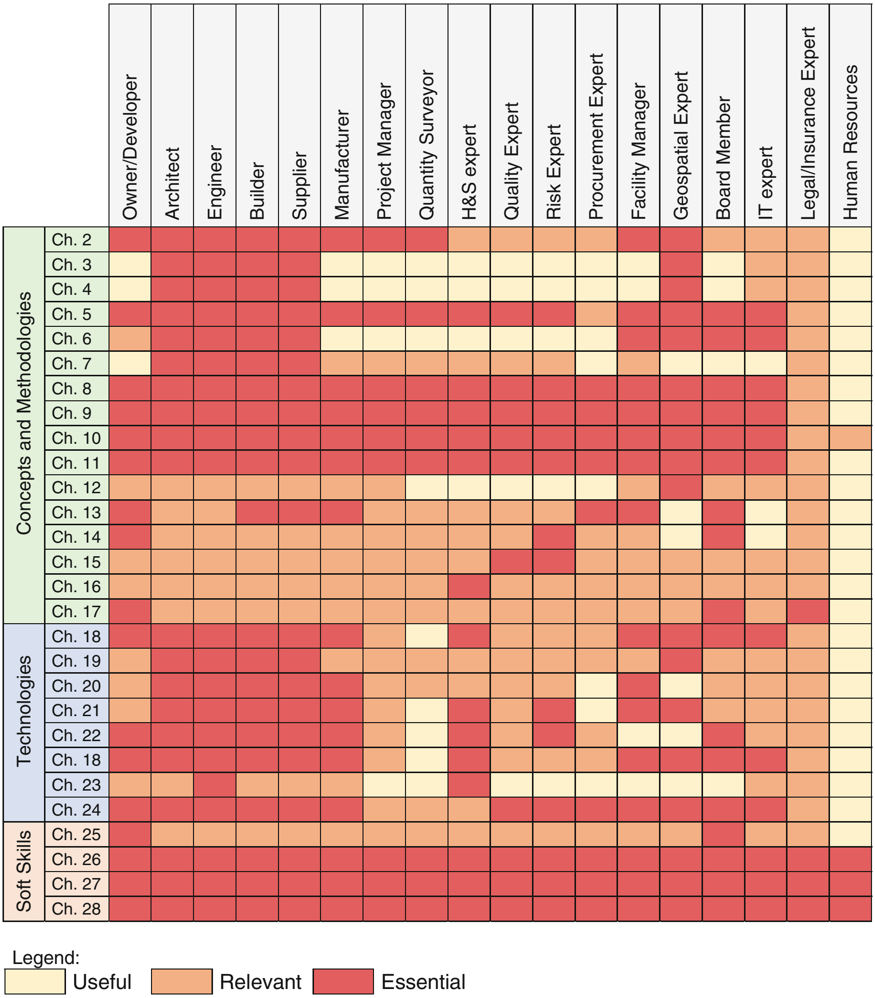

Fig. 8 Quick guide for current professionals to select the book contents essential or highly relevant for their professional growth in Construction 4.0

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