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TITOLO DELLA TESI: A Journey into Digital Construction: An enquiry on the nature of digital transformation from the EU perspective

TESI PRESENTATA DA: Davide Meinero

TUTOR: Professor Valter Cantino

COORDINATORE DEL DOTTORATO: Professor Stefano Bresciani

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A Journey into Digital Construction

An enquiry on the nature of digital transformation from the EU perspective

Table of contents

Abstract

In recent years, the construction industry has embarked on a process of digital transformation that will revolutionize what the sector will look like a few years from now. Following the path and the trajectory of other sectors, digitalisation is gaining momentum in the construction sector due to the rapid spread and adoption of digital technologies by an increasing number of companies. The change is first and foremost driven by the rise in digital and data platforms that are bringing substantial benefits to the sector, such as a better communication as well as an enhanced data exchange among the economic players. Future competitiveness will depend on the ability to master data and AI technologies and to build new forms of collaboration with other players all along the value chain to better serve future market needs in a more comprehensive way.

The Digital Revolution is already impacting the sector from several points of view, in particular business process management, skills, competencies, and regulation. All of these points will be carefully scrutinized in the following pages.

Chapter 1 will introduce the discussion by focusing on the most important traits of the data and platform economy, that are then repeatedly cited in the following chapters when investigating the digitalisation phenomenon in the construction sector.

Chapter 2 contains the results of an IT driven systematic literature review of digital construction, and it represents a starting point for the next steps in the research.

Chapter 3 is an investigation on digital construction, and it focuses on those aspects that will be significantly impacted by the digital revolution underway.

Chapter 4 describes the EU digital strategy by highlighting the relevant regulatory and policy elements on data and artificial intelligence as well and on the industrial strategy that will have an impact on the digital revolution in the EU.

Chapter 5 builds on the results of the previous chapter and it focuses on EU initiatives in support of digitalisation of the construction sector with the example of a relevant pioneer case study on a digital industrial platform.

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1. Introduction

i. An overview on the data and platform economy

This first introductory chapter contains some reflections on the research work conducted in recent months and years, on the subject of the digitalisation of the construction sector. It is my intention to set the scene and to give the reader some relevant elements for a better interpretation of the different chapters and to make sense of the entire study. I'm confident that while going through the pages the reader will be progressively immersed in the world of digitalisation and identify the thread that unites and connects all the parts of the current study. Spoiler alert: the content of the following pages is intended as a snapshot on the data economy based on the conclusions I have drawn from a long and fascinating journey into digital construction. The choice of the construction sector is far from being accidental. In fact, due to the unique characteristics inherent in the construction sector it represents an extraordinary case study[1] wherein to investigate the dynamics of digitalisation and digital transformation. This subject cannot be separated from the importance of the "platformization" trend that is directly linked to the digitalisation phenomenon and which is also the object of some significant EU funded projects. As a commonly recognized definition of platformization is still lacking, I decided to adopt a neutral approach by defining it as "the introduction and adoption of digital platforms at industry level and the subsequent impact of the same on business models." I deliberately chose not to limit the interpretation to the corporate dimension because of the ecosystemic nature of platforms, that extend far beyond the boundaries of single organisations given that they lie at the core of complex networks of relationships among various stakeholders.

There is another aspect worth mentioning, when running a preliminary literature review by limiting the research to the terms "data economy" on various scientific

[1] Feagin, Joe R., Anthony M. Orum, and Gideon Sjoberg, eds. *A case for the case study*. UNC Press Books, 1991.

databases[2], it transpired that the number of available articles is still limited. In most cases the "data economy" is not treated as a subject *per se* but as part of a broader discussion on other directly connected aspects, such as Big Data, sharing economy, privacy and personal data management, social media ethics to name just a few. However, by modifying the research questions to investigate the "platformization" trend, relevant aspects emerge such as co-evolution platform architecture, services and governance,[3] the importance of platforms as market places[4], the new business models linked to the adoption of digital platforms with a focus on some specific sectors,[5] the potential of such platforms to tackle societal challenges,[6] and the interaction of digital platforms with other disruptive digital technologies such as blockchain,[7] to mention just a few. All these aspects are very important to a better understanding of digitalisation, which I will describe in the next pages. Therefore, I will constantly reference the platform element while continuing the discussion on the data economy, given that it represents a highly representative enabling factor.
For the time being, what really matters from my point of view is to firstly set a clear framework to define the essential characteristics of the data (and platform) economy, in particular what makes it unique vis-à-vis other types of economy (e.g. digital economy). It is my opinion that this framework is of paramount importance in understanding the fundamentals of digitalisations, independently of the sector and it should be a valid support for the reader to be guided in the upcoming chapters. For the sake of clarity, I wrote this specific section at the end of my research journey into

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[2] The systematic literature review was conducted on different scientific databases such as ScienceDirect, JSTOR, Scopus, SpringerLink, Web of Science.
[3] Marin Jovanovic, David Sjödin, Vinit Parida, *Co-evolution of platform architecture, platform services, and platform governance: Expanding the platform value of industrial digital platforms*, Technovation, 2021.
[4] D. Mourtzis, J. Angelopoulos, N. Panopoulos, *A survey of digital B2B platforms and marketplaces for purchasing industrial product service systems: A conceptual framework*, Procedia CIRP, Volume 97.
[5] Néstor Duch-Brown, Fiammetta Rossetti, Digital platforms across the European regional energy markets, Energy Policy, Volume 144, 2020.
[6] Shantanu Mullick, Néomie Raassens, Hans Haans, Edwin J. Nijssen,
Reducing food waste through digital platforms: A quantification of cross-side network effects, Industrial Marketing Management, 2020.
[7] Aneesh Zutshi, Antonio Grilo, Tahereh Nodehi, *The Value Proposition of Blockchain Technologies and its impact on Digital Platforms*, Computers & Industrial Engineering, 2021.

the dynamics of digital construction in order to have a broader picture. I specifically choose to use the construction sector as a case study to identify and/or confirm some traits that are typical of the data and platform economy. This field of research is still relatively recent, but it is developing extremely fast due to the speed and the import of the digital revolution.

It is now time to outline a picture of the data and platform economy based on my interpretation of several readings that I considered particularly interesting to the scope of this research cross referenced with the results of the overall enquiry on the nature and dynamics of digital transformation in the construction sector.

Let us start from the first relevant aspect: data. In all the studies analysed during the desk research as well the results of the interviews that I personally conducted with the members of the construction sector; data emerged as the distinctive feature of the current digital revolution. That means that the successful evolution of the sector will strongly depend on the way technologies and techniques to collect, analyse and interpret data are adopted. This point is also mentioned in a number of studies that have been conducted by the European Commission in the recent years and that were used as a basis for EU public policy on digitalisation and digital transformation as described in chapter 3. In one of these studies, the data economy is defined as "the financial and economic value created by the storage, retrieval and analysis – via sophisticated software and other tools – of large volumes of highly detailed business and organisational data at very high speeds."[8]

In the communication, *Building a European Data Economy*[9] some important elements for a thriving data economy were identified such as the importance of free flow of data for the new data-driven opportunities to be seized, the need of having governance mechanisms and technical solutions to guarantee the access and the easy transfer of data among different market players to favour the emergence of new and innovative solutions. In addition, liability issues as well as "portability of non-personal data, the interoperability of services to allow data exchange and appropriate

[8] Digital Reality, Data Economy Report 2018. See here: https://www.digitalrealty.com/data-economy
[9] COM(2017) 9 final, *Building a European Data Economy,* 10 January 2017.

technical standards for implementing meaning portability"[10] are already mentioned as being important elements for a well-functioning data economy.

Let us go back to the relevant aspects of the data economy. First, the size. As indicated in the *Final Study Report: the European Data Market Monitoring Tool* "the value of the data economy of EU27 was almost €325 billion in 2019, representing 2.6% of GDP. The same estimate predicts that it will increase to over €550 billion by 2025, representing 4 % of overall EU GDP."[11] Some studies state that the volume of data produced in the world is rapidly growing and that it will increase from 33 zettabytes in 2018 to 175 zettabytes in 2025[12], thus raising new challenges for data storage, curation and management. According to the Statistica report, in 2025 the total number of connected devices in the world will reach approximately 75 billion compared to 30 billion in 2020,[13] thus leading to a boost in data generation in the years to come.

Second, nature. Data is often considered the new oil of the digital age in the sense that "[…] just as oil is the base for many industrial activities, data has now become the input for many services and industries that are interconnected through digital pathways."[14] But this comparison is misleading as it does not take into account the inner nature and characteristics of data, that make it unique *vis-a-vis* other goods and services. Data is a non-rival good, meaning that it can be used by many people at the same time. It turns out that the benefits derived from data are higher when used by a multitude of people (or entities) compared to when it is used by a single individual."[15] But there's more. If properly managed, data can indeed help achieve economies of scope. "Economies of scope occur when the benefits of analysing/using a joint data

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[10] *Ibid*. page 15.

[11] *Building a data economy – Brochure,* available here: https://ec.europa.eu/digital-single-market/en/news/building-data-economy-brochure. The estimates already take into account the economic downturn caused by the COVID-19 crisis, but a certain margin of error might still exist.

[12] COM (2020)66 final, *A European strategy for data*, page 2.

[13] T. Alam, *A Reliable Communication Framework and Its Use in Internet of Things (IoT),* International Journal of Scientific Research in Computer Science, Engineering and Information Technology, May 2018.

[14] S. Kumar, Sree, et al. *The Data Economy: Implications from Singapore*, Routledge, 2018, page 7

[15] JRC Digital Economy Working Paper 2018-09, *The impact of data access regimes on artificial intelligence and machine learning*, Bertin Martens, page 11.

set are higher than the sum of benefits of analysing/using each dataset separately: V(d1,d2) > V(d1) + V(d2). These benefits occur when there is a relationship between the two sets, i.e., when they are not completely separable and data that pertains to one situation may also be relevant to another situation."[16] This characteristic explains the "barter" trade in data, or the exchange of data in return for "free" services" that are the result of the aggregation of data from several sources. Last but not least, data can help achieve economies of scale. While significant upfront investments (i.e. fixed costs) are necessary to obtain high quality and large datasets for training of algorithms, "once they are trained […] the marginal cost of additional use of the algorithm can be very low thus giving rise to potential economies of scale […]."[17] All these features explain the importance of having clear and transparent data governance mechanisms that favour data sharing and data access[18] in order to have a thriving data economy.

Third, the impact. The market of data is growing very fast, and individuals, firms, and governments are increasingly aware of the importance of data. For the sake of clarity, this is "not to suggest it is a replacement for the real goods and services sectors, but an augmentation of the current economic structure, with data becoming an important ingredient in creating and, in some cases, destroying value."[19]

It is worth mentioning that "the growth in data and the analytics that accompany it will have a significant impact on digital intermediation." Specifically, an increasing number of companies are now specializing in different types of services related to data capture, storage, secure transmission and cybersecurity. In order for the data economy to thrive, the prerequisite is the wide spread of digital technologies and proper infrastructure, from high-speed computing to cloud services, from efficient IoT technologies to fast communication protocols. In addition, in order to exploit the potential of data science, processes all along the value chain must be progressively

[16] *Ibid.* page 9.
[17] *Ibid*.
[18] Considered the complexity of the issue, it should come as no surprise that this subject involves a variety of different fields in economy and legal theory, from competition to intellectual proper rights.
[19] S. Kumar, Sree, et al. *The Data Economy: Implications from Singapore*. Routledge, 2018, page 8.

integrated so as to favour a smooth seamless cycle of data collection, transmission, analytics and output generation that will produce innovative high added-value solutions. The marketplace is currently characterized by the presence of a few well-known giant corporations such as Google, Apple, Amazon, Facebook, Microsoft, IBM that already provide a wide array of data services but "there are several other (players) of significance in this wide data space". While some are large, the majority "are smaller companies that fill niche areas such as in data aggregation and data analytics."[20]

The growing presence of digital intermediaries is also deeply affecting the traditional sectors such as manufacturing, agriculture transportation and also the construction industry, as will be extensively discussed in the coming pages. More and more industrial players have turned to external intermediaries (i.e., platforms) for services such as data storage, processing, and analytics in order to provide their customers with innovative data-driven added value solutions. The growing collaboration between traditional actors and IT players is therefore reconfiguring the marketplace, thus leading to a "flat and networked structure of industries and services" and ultimately modifying the very nature of work itself. "Repetitive tasks are being automated, while even once highly professional services […] are being invaded by AI, which can sift through masses of big data to identify important patterns, precedents, and immediate trends. The change is essentially towards a new class of knowledge-intensive work, which requires creative and quantitative skills."[21] In turn, this also means that tech giants might increasingly erode the market share traditionally occupied by other traditional industries thanks to their enhanced capacity to discretize and automatize processes as well as to offer new solutions based on data science. In that regard, we might expect the gradual rise of new "hybrid" conglomerates capable of pooling together the expertise of capital-intensive industries

[20] Kumar, Sree, et al. *The Data Economy: Implications from Singapore*. Routledge, 2018, page 15.
[21] *Ibid*. page 10.

(e.g., automotive, capital goods, construction machinery) and IT knowledge[22] to address the challenges and fulfil the market needs in the new digitalized society. The speed of change is impressive, and governments might come late or fail to grasp the big picture and to fully understand the size and the impact of the current revolutionary processes linked to the adoption of digital technologies. As stated by some researchers, "a traditional economy is defined as having the factors of production – land, labour and capital – used in a formulaic manner so as to create outputs from specific input materials." However, "as the number of producers changes through, for example, mergers and acquisitions, there may arise oligopolies and monopolies that arise to control the quantity and price of products"[23] thus requiring government intervention to prevent abuse of market power with the aim of protecting consumers and other smaller competitors that run the risk of being cut out from the market. In this context, if data is the fundamental raw material for the new digital economy to thrive, particular attention should then be placed on the monopolistic behaviour of some corporations that act as gatekeepers and prevent fair and transparent access to data. This point in particular inspired the recent choices of the European Commission. While in the traditional economy *ex-post* competition law measures could be enforced to prevent these kinds of situations from arising, because of the speed of the digital economy, consensus is emerging in favour of more *ex-ante* vigorous actions[24] before the list of potential bankruptcies or acquisitions become too long due to unfair competition. Still on the regulation side, elements such as privacy, confidentiality and security, all elements that contribute to a trustworthy economy, are at the centre of the debate. In the case of personal data protection, GDPR adopted in the EU has become an example and a reference also for other countries, as

[22] This reflection is driven by the example coming from other sectors. In particular, I'm referring to WAYMO, the autonomous driving technology development company or Disney's whose interest in buying AMC movie theatres to distribute its own movies has attracted the attention of several analysts.
[23] Kumar, Sree, et al. *The Data Economy: Implications from Singapore*. Routledge, 2018, page 8.
[24] This topic has been extensively discussed in a series of debates broadcasted by France Culture, such as *Concurrence: l'Europe passe à l'offensive?*, *Régulation des Gafa: l'Europe a-t-elle les moyens de ses ambitions?, Numérique: comment l'Europe peut-elle réguler les GAFAM ?*, that saw the participation of several prominent scholars and experts.

explained in chapter 3. At the same time, there is still a lot to be decided in the area of non-personal data, that is clearly going to rise exponentially due to the adoption of digital technologies in the construction sector. In this sense, the EU strategy assigns, governments and public administrations, in their role of major users and suppliers of data, a major role in "leading by example" so as to incentivize protected, secure and fair data sharing among parties, especially in the achievement of outcomes in favour of the common good. On the impact side, skills and organizational culture are going to be deeply affected. On the one hand, the increasing need of having employees with a high level of expertise in algorithm, coding and data science will require more knowledge-intensive scientific and engineering skills. These skills will be required not only in technical areas but also in "framing decisions by acting as an advisor on the types of analytics to be done and communicating these in an understandable manner to others in the corporate hierarchy at one level and being able to understand the business and its demands so that the outputs can be tailored to the requirements of strategy, finance, and operations at another."[25] On the other hand, organizational culture will also be deeply affected. New methods such as higher delegation, flat organizational structures based on horizontal cooperation among different multidisciplinary teams, a higher risk-taking culture and a more outcome-oriented action approach, more typical of the R&I industry, are now increasingly considered to be essential features for the new data economy.

In conclusion, the new data economy is generally characterized by a profound phenomenon known as "platformization". In this context, the platform is intended as a digital ecosystem that connects, objects, and companies through a seamless and constant exchange of data that enables the rise of new innovative solutions thanks to advanced analytics and data processing capable of making sense of the complexity. This way companies can easily be in touch with partners and customers, share data and co-create products and services, combine expertise, thus favouring higher participation of customers while boosting profits and generating network effects. In

[25] Kumar, Sree, et al. *The Data Economy: Implications from Singapore*. Routledge, 2018, page 24.

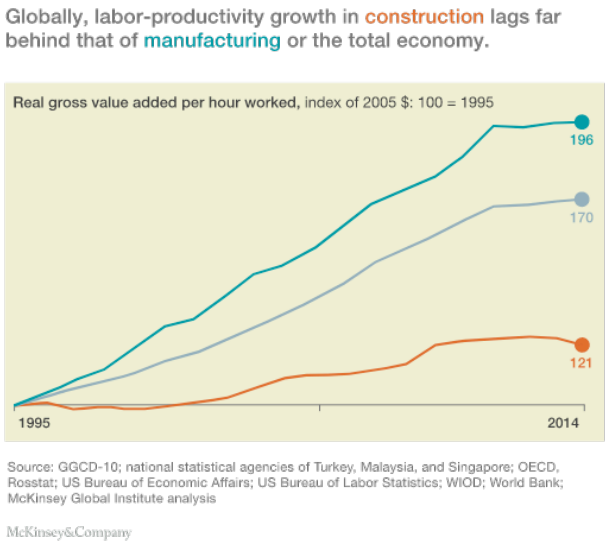
that sense, the elevated and seamless interconnection among parties can potentially blur the boundaries of the organizations thus opening the way for the adoption of new and inclusive business models that will favour the creation of higher shared value, as I will outline in chapter 3.
It is now time to turn to the object of the research: the construction sector.

ii. The construction sector as a case study

The choice of this subject for the research has been driven by three major considerations: an academic one, a policy one and an ethical one.
Concerning the academic aspect, while observing and analysing previous research in the sector, and especially based on the results of the Systematic Literature review of chapter 2, I realized that there was significant room for research on the subject. On the one hand, digital transformation in the construction sector is still a recent phenomenon, and as such it has been only partially explored. Secondly, research on digital construction is usually focused on the engineering and technological aspects, while important gaps need to be filled on the importance of data and AI for the generation of innovative and substantial solutions with significant added value. In fact, an increasing number of studies tend to confirm that digitalisation cannot only be limited to technological considerations, the company culture, organization, and in turn the management practices, play a fundamental role in ensuring the success of digital transformation.
Concerning the policy aspect, the size and the relevance of the sector makes it particularly important for policymakers. The Architecture, Engineering and Construction sector can without doubt be considered one of the pillars of the EU economy. With more than 3 million enterprises and 18 million workers, it represents more than 9% of the EU GDP[26] and the 43.2% of gross fixed of capital formation in the EU27 (2019 data).[27] The sector is widely dominated by SMEs, in particular micro

[26] *Digital Transformation in Transport, Construction, Energy, Government and Public Administration*, JRC Science for Policy Report, 2019, page 99.
[27] *Key figures 2019*, *Construction activity in Europe*, edition 2020, FIEC.

enterprises: according to EUROSTAT 94% of construction firms had 9 or less employees in 2016. However, according to several reports the level of productivity has been stagnating in the recent years when compared to other sectors such as manufacturing.



Source: McKinsey&Company

This is also due to low level of digitalization: the fact that only 7.7% of enterprises have a high of very high Digital Intensity Index[28] while 70% of construction firms dedicate less than 1% of their revenues to investments in innovation, in particular digitalisation.[29] At the same time, the construction sector has one of the greatest economic knock on effects: according to McKinsey[30] every construction GDP dollar represents an additional benefit of $2.86 to the economy. Therefore, even a slight change in the sector can potentially generate a huge impact on the overall economy. In that regard, digital transformation represents potentially a disruptive factor to boost productivity and favour economic growth. Some scholars believe that the construction industry, due to its size and structure, as well as its output and its

[28] DESI Key indicators https://digital-agenda-data.eu/
[29] JB Knowledge (2016) and McKinsey.
[30] *Reinventing construction – A route to higher productivity*, McKinsey, February 2017.

contribution to employment in the country and quality of life has the potential to produce a substantial «multiplier effect» consequently, the construction sector can be treated as an economic regulator.[31]

Concerning the ethical aspect, the construction industry can potentially benefit from the digital revolution in various ways. The construction sector has a significant impact on energy and resource efficiency. Let's look at some numbers: "the sector accounts for about 50% of all extracted material" and "it is responsible for over 35% of the EU's total waste generation". Moreover, "manufacturing of construction products, as well as construction and renovation of buildings are estimated at 5-12% of total national GHG emissions."[32] Also on the safety side, according to EUROSTAT[33] in 2018 the construction sector accounted for one fifth (20.5 %) of all fatal accidents at work in the EU-27 and 11.6 of non-fatal accidents. In that regard, the adoption of innovative digital solutions can fundamentally alter these numbers for the better thus contributing to an improvement in environmental and societal conditions as well as to the overall image of the sector, which still tends to be viewed as dull, dirty and dangerous – which in turn makes it less attractive to younger generations and women. In that sense, digital applied technologies should bring a considerable improvement to each of the abovementioned points.

Methodologically speaking, the research combines desk research with a series of in-depth interviews[34] with some relevant representatives from the construction sector and from the EU Commission. I started from research, previously conducted on the sector (*Digitalising the construction sector – Unleashing the potential of data with a value chain approach*[35]) published in January 2019 which I reinterpreted in the light

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[31] *Economic regulator: The UK Construction Industry*: https://www.mcmdev.com/stories/economic-regulator

[32] Buildings and Construction, https://ec.europa.eu/growth/industry/sustainability/built-environment_en

[33] Accident at work statistics, 2018: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Accidents_at_work_statistics#Number_of_accidents

[34] Alvesson, Mats. *Interpreting interviews*. Sage, 2010.

[35] *Digitalising the construction sector – Unleashing the potential of data with a value chain approach*, CECE, January 2019. The research was sponsored by the CECE and is available here: https://www.cece.eu/news/cece-digitalisation-project-results-are-published.

of additional and more updated information on the subject. Another relevant report proved to be particularly relevant to obtaining a comprehensive view on the sector's evolution: *Digital Transformation in Transport, Construction, Energy, Government and Public Administration.*[36] Desk research was a fundamental step to prepare the questionnaire for the in-depth interviews, that allowed me to collect significant insights on the digitalisation of the construction sector from the direct experience of those involved. To make it more representative, the interviews were conducted with several actors in the value chain, notably to representatives from academia, those with EU level association and from the industry (both on the contractor and on the OEM side) in order to obtain a more comprehensive view of the direction the sector is heading in.

In chapter 4 and 5, the theme of digital construction is analysed through the lenses of the EU policy on digitalisation. This choice was deliberate, and it was driven by the assumption that, given that governments are the most important client of the construction industry, the process of digital transformation of construction will be significantly influenced by the choices taken on this subject by public authorities. In particular, I deemed it important to focus on the initiatives taken at EU level because I'm convinced that the European way for the Digital Decade will impact the sector under several aspects. The content of these two chapters is the result of analysis of the EU official literature combined with in-depth interviews with some EU officials, in DG CNECT and DG GROWTH, who are involved in the process of policymaking on the subject.

In summary, the research contained in the following chapters presents the major trends in the digitalisation of the sector, with a particular focus on the importance of data and the exploitation of the same in the creation of new added value solutions, with the aim of shedding some light on the nature and dynamics of digital construction from an EU perspective.

[36] *Digital Transformation in Transport, Construction, Energy, Government and Public Administration*, JRC Policy Report, January 2019.

2. A systematic literature review on digital construction

i. Introduction

The research began with a systematic literature review (SRL) to evaluate the state of the art of the research into digital construction and to better orient the interviews both with the representatives from the construction sector and the EU officials. In this context, I intend the (SLR) as a "a review of an existing body of literature that follows a transparent and reproducible methodology in searching, assessing its quality and synthesizing it, with a high level of objectivity. *"*[37]

The SRL proved to be of paramount importance in identifying trends and weaknesses on the subject and, consequently, to bringing some original results to the current research.

The SRL was conducted on a sample of 141 articles on digital construction. Specifically, the aim of this work was to review the existing literature on the subject of digital construction in order to broaden the discussion contained in the previous chapter, that is first and foremost based on the results of the qualitative in-depth interviews "in the field" to members of the construction sector crossed with desk-research on a series of sectorial reports from EU institutions (i.e. JRC, CEDEFOP) and several consulting agencies (i.e. Boston Consulting Group, Deloitte, Innovation & Development Consulting). The SLR exercise was of paramount importance to identify both trends related to the digitalisation phenomenon in the sector and therefore to draw parallels with the results from the previous chapter as well as to identify potential gaps in previous research, which in turn proved to be very inspirational in the preparation of a new questionnaire for additional ex-post interviews that were used to fine-tune the entire work.

Concerning the methodology, given that the research was on the theme of digitalisation, I opted to adopt digital techniques in order to obtain un-biased and

[37] S. Kraus, M. Breier, and S. Dasí-Rodríguez. *"The art of crafting a systematic literature review in entrepreneurship research"* International Entrepreneurship and Management Journal 16.3 (2020): 1023-1042.

solid results in the research area I was addressing. For that purpose, I was supported by the expertise of Net7 Srl, and in particular Luca de Santis (CTO), Nicola Salerno and Sebastiano Martorana (both interns at Net7) for the design of the research tool and for the subsequent testing of the various IT tools identified for the launch of the SLR. To verify the effectiveness and subsequently adopt the most appropriate IT methodology for the SRL, we run several tests and iterative trials which allowed us to compare the results of different techniques as well as to verify the effectiveness of the results. In the end, two techniques (LDA and BERT) were selected for the purpose of the research. The outcome presented in this chapter is therefore the result of a dynamic process that entailed constant interaction between the IT experts and the domain expert (the researcher). Significant research was also carried out on the IT side in order to fine-tune the process to fulfil the pre-set objectives and achieve reliable results. Let's look at the methodology and results, in depth.

ii. Methodology

A significant evolution has occurred in recent years in the field of Natural Language Processing (NLP), that is, the processing of natural language by machines through the training of increasingly complex and articulated machine learning models, along with the advent of the gpu (GraphicsProcessing Unit) and tensor processing unit (tpu) with out-of-the-ordinary computational capabilities, that lend themselves well to achieving the SLR's objectives of classifying and grouping a collection of scientific texts related to a given sector of interest.

Text interpretation is done by models that automatically process documents (abstract articles, full texts, or parts of text within them), while grouping models (clustering algorithms) bring together similar documents based on common concepts. Data extraction models attempt to identify text fragments or individual words that correspond to a particular variable of interest. Finally, text grouping models (clustering algorithms) attempt to group similar documents by common topics and concepts.

The purpose of the work was the implementation of an automatic, scalable, and efficient system, able to automate the execution of SLR on a corpus of scientific papers published in the field of digital constructions. The work is based on the need to create an effective tool that can help in the selection, classification, and representation of literature in a highly innovative, technological, and avant-garde sector such as digital constructions in which the latest innovations and inventions of industry 4.0 and smart manufacturing find expression and use.
In particular, the project takes place on several levels of analysis, moving from words to documents, and algorithmic complexity to produce the following objectives:

a) Extraction of similar document groups by clustering techniques.
b) Extraction of the main topics by extracting the words representative of each cluster of documents identified.
c) Summary of the texts contained within each cluster.

The choice of texts was decided based on a series of keywords derived from previous research carried out by me in the field of "digital construction". Hot and recurring themes in the literature selected for the work are the digitization and computerization of the construction processes and applications of new cutting-edge technologies.
The search for papers was restricted to 141 articles selected on the database Science direct[38] by using the keywords “digital construction” and “digital transformation construction” and by limiting the research to the articles published between 2015 and 2020.[39] The initial corpus of documents to be analysed was composed of 45 texts (in pdf format). Subsequently, to try to make the domain as large and heterogeneous as possible with a view to increasing the quality of clustering, more papers were added for a total of 141.
Initially, in the pre-processing phase, texts were converted to .docx format and metadata such as title and keywords was extracted where present. Then, with the new

[38] www.sciencedirect.com
[39] For the complete list of articles, please refer to Annex I at the end of this work.

format that allowed, unlike pdf, the exploitation of the paragraph subdivision, the keywords, abstract and remaining whole text were extracted, starting from the structure. Missing or incomplete parts have been added by hand. To work on a single document and easily access each text and section of the text, a json file was specially created containing each text made up of the respective parts.

a) Models

In order to create a vector space for representing the corpus of documents, a number of NLP models were considered and tested, starting with simpler and more traditional models such as the TF-IDF, then progressing through recent word embeddings such as Word2vec and FastText, to contemporary pre-trained transformers, such as BERT and T5.

Each model was initially created in two versions: one having only the title as input, abstract and keywords of each paper; the other built on all the text in the paper. Once it was concluded that the use of the full document gave better and more stable results, the choice fell firmly on the second version. After repeated experiments, *Latent Dirichlet Allocation* (LDA) was chosen, which is explicitly aimed at the topic model. This is a type of statistical modelling to discover and extract abstract arguments that occur in a document library. LDA is therefore a template used to classify the text of a document into a particular topic. In addition to the inherent function of topic extraction, and similar to what happens in the case of clustering, this model can assign each item to a specific topic.

In this case, the documents were considered in full. Tokenization was made, special characters, punctuation, and stop words were removed, lemmatization was made, and *bins* were obtained. The *bag of words* obtained is ready to be transformed into a scattered matrix. Unlike the TF-IDF, each token is assigned the *term frequency* (*tf*) only value resulting from the simple word count.

To avoid getting topics that are too generic and potentially appear with an elevated frequency in all documents, *the max df* parameter, used to remove data values that

appear too frequently, was set to 0.7, so as to ignore terms that appear in more than 70% of documents. To avoid extracting topics that are exclusive to a single document, the min df parameter, used to remove terms that appear too rarely, was set to 2 so as to ignore terms that appear in less than 2 documents.

To avoid terms that are too general, the maximum number of significant terms was limited to 2000. To obtain significant expressions (*collocation*) and not only single terms we set the *ngram range* = 3.

Regarding the actual execution of the LDA algorithm, following a series of experiments the number of topics to be extracted was set at 15, in an attempt to reach a good compromise between exhaustiveness and comprehensibility of the contents.

Below is a preliminary image related to the distribution of documents in the various topics identified, that was further refined in the finalization phases.[40]

```
topic8-->  n.documents 4
topic3-->  n.documents 13
topic5-->  n.documents 10
topic0-->  n.documents 8
topic6-->  n.documents 8
topic7-->  n.documents 10
topic13-->  n.documents 13
topic14-->  n.documents 10
topic4-->  n.documents 7
topic1-->  n.documents 14
topic12-->  n.documents 26
topic9-->  n.documents 7
topic2-->  n.documents 6
topic11-->  n.documents 5
topic10-->  n.documents 2
```

b) Distribution of articles for topics extracted from LDA

Based on the analysis of the list of keywords extracted from the template the following topics were identified.

[40] For the analysis of this results, please refer to the following section.

CLUSTER	TOPIC
12	Digital construction management
13	BIM in digital construction
3	Fabrication methods, materials, and techniques
1	Education and training in support of digital construction
2	Digital systems for monitoring construction processes
5	Digital imagery for construction
14	Emerging technologies in construction
6	Safety and risk management 6
0	Materials' properties
9	New skills and competences
4	BIM in project lifecycle management
7	Monitoring the construction processes
11	Digitalisation in civil engineering
8	Data collection requirements
10	Blockchain in construction

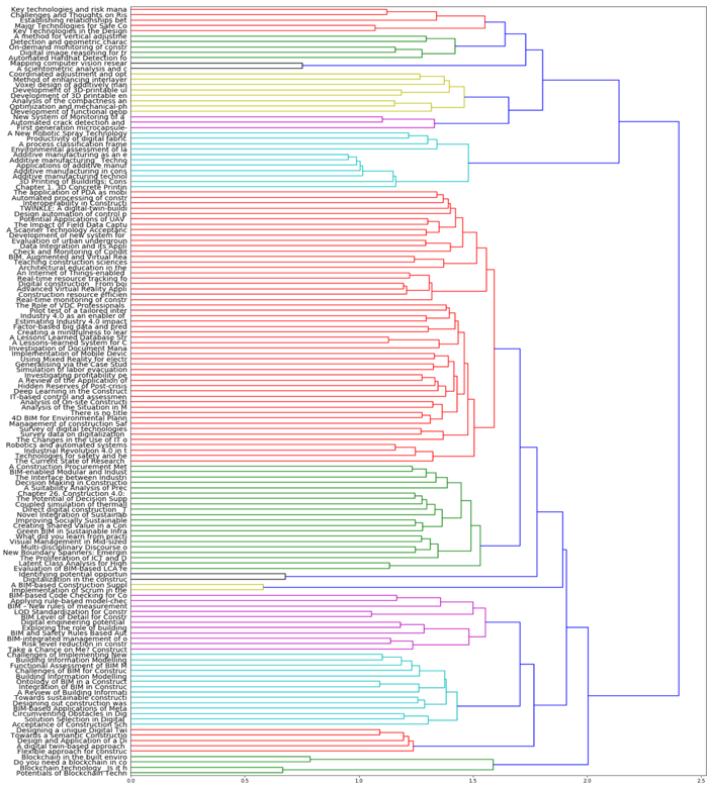
For each article, the algorithm quantified the probability of belonging to each topic. Based on this probability and the label assigned by the domain expert[41], an example of grouping items by topic (the words in bold can be traced back to the label) is given below. For a comprehensive justification of the choice of cluster number and LDA topics, please refer to the next paragraphs.

The clustering algorithm chosen to group similar texts was hierarchical *clustering*. Hierarchical clustering is an algorithm that produces a set of clusters organized into a "tree" structure. It can be displayed as a dendrogram, i.e. a tree diagram representing a progressive sequence of ever larger groupings. With this model it is not necessary to define the number of clusters a priori, which can be obtained by 'cutting' the dendrogram to the appropriate level. It can identify a taxonomy (hierarchical classification) of concepts, where elements that are similar to each other are grouped together ahead of those which display less similarity, until a single large cluster including all elements is obtained.

[41] When referring to the domain expert in the experiments done to test the method, I intend the author.

Because the hierarchical clustering algorithm is based on calculating the distance between elements and not assigning each element to a randomly generated centroid, the results are more stable, more balanced, and therefore more easily interpretable. In addition, the repeatability of the output made the comparison between NLP models independent of random factors and consequently more objective.

The second hub and crucial point of the work was the transition from 10 to 15 clusters, to come up with more homogeneous and less confused groupings. In some cases, with only 10 clusters, some documents with diverse topics ended up being grouped together, preventing cluster homogeneity. At the same time, the number of topics resulting from the interpretation of outgoing keywords from only 10 clusters led to the loss of some relevant topics. On the other hand, the move to 15 clusters made it possible to get homogeneous groupings, which are easily distinguishable from each other and more comprehensive in terms of *topic extraction* (see image below).



c) Summarization

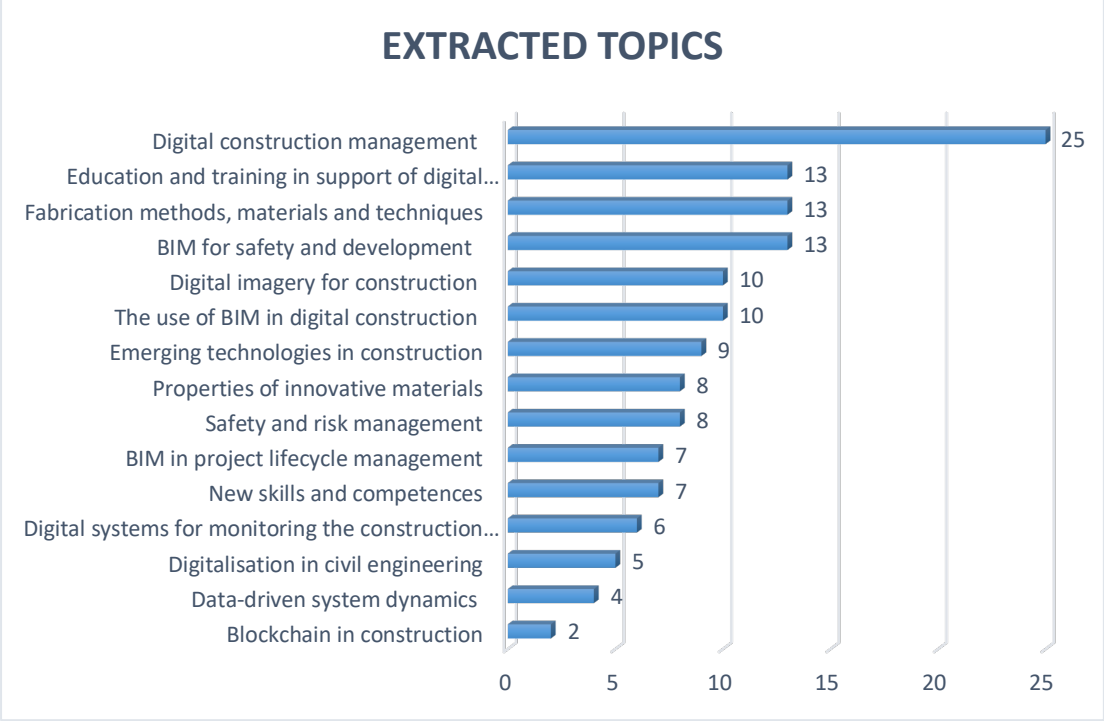
The final task of the work was to summarize the clusters of the documents identified, passing through the extraction of the topics characterizing each of them. After several iterative tests, the choice on the best method fell on BERT.
BERT, an extractive model, can process very long texts, without the typical limitation of 512 tokens of input inherent in the version aimed at extracting embeddings. The absence of such a limitation made it possible to extract the summary from the merger of the abstracts present in each cluster. The summary resulting from the application of the model, similar in length to that of an abstract, coincides with the merger of the most important sentences *that are extracted* from the input text. The summaries of the clusters carried out with BERT, although not very linear from the linguistic point of view given the extractive nature of the model, are detailed and understandable.
Below is a summary of one of the clusters extracted with the best identified model, *BERT Extractive Summarizer*.

> ***Materials and materials' properties, 3D Printing, materials and fabrication methods***
>
> *3D Construction Printing (3DCP) is a new and emerging technology that is set to revolutionise construction. At present, the technology is in its early stages of development and many hurdles are yet to be overcome. Conventional, mold-cast ECCs were also prepared and tested for comparison purposes. This finding is in good agreement with the results of the microstructural analysis. The implementation of self-healing techniques as part of repair methodologies in extending the service life of concrete structures has great relevance as it cannot only guarantee direct and timely ratification in the construction industry but also transform the outlook of existing infrastructure. Several fresh and hardened state properties of the 3D-printable UHPFRC matrix (without fiber) and composite (with 2% volume fraction of steel fibers) were evaluated and compared to that of conventional mold-cast UHPFRC. The high compressive and*

flexural strengths, along with the deflection-hardening behavior, of the developed UHPFRC can enable the production of thin 3D-printed components with significant reduction or complete elimination of conventional steel bars. The effect of water content on the mechanical performance and physical properties of synthesized geopolymers was evaluated. The residual soluble salts in produced geopolymers were markedly reduced by using this optimum water content.

iii. Cluster analysis and presentation

Thanks to the results achieved using the methods mentioned above, it was possible to conduct a comprehensive analysis by focusing both on the distribution of the articles per topic, thanks to the classification done with the hierarchical model, and then to focus on the content obtained through the use of the summarization technique.
The table below shows the list of the clusters identified with the LDA technique and the number of articles that belong to each of them in decrescent order.



From the analysis of results, one cluster emerged as more densely populated when compared to the others: Digital construction management. As discussed in the next chapter, this is due to the particular cross-cutting nature of digital technologies that impact horizontally all construction processes therefore enabling decisions at management level.

In the paragraphs below, I will first start by showing the contents of the clusters identified in the table above. Methodologically speaking, the synthetized abstract required a three-step process.

1. the content extracted with BERT were carefully analysed. In general, the result of the extractive technique looks like an abstract where all (or at least the majority) of the topics included in the clusters are merged together. The rough version of the abstract is not always sufficient to clearly identify the deep meaning of each cluster. This is due to the fact that the extraction technique is addressed to a pool of articles with very close similarities, thus making it more complicated to clearly identify the nuances in the content while running the first taxonomy exercise.
2. When inconsistencies are detected, a comparative analysis both with the list of titles mentioned in each of the cluster and with the original abstracts is necessary to address gaps and harmonize the content. This is particularly useful in making sense of the cluster content and to identify potential nuances in the presentation of the same topic. In this case, the choice fell on BERT because the results proved to be more complete. However, compared to other techniques, the drawback is the loss of the stylistic presentation, thus forcing the research to further fine-tune the content.
3. In the final phase, a synthesis work is done and the final version of the summarized abstract of the cluster is prepared. In most of the cases, the deviation of the final version compared to the initial BERT “rough” one was only minimal. However, where the content was considered to be unsatisfactory, consistent changes were brought to the text. In this case, in phase 2 a deeper investigation on the content of the articles was necessary to clarify the content of the summary and

to reach a reasonable level of accuracy. At the very end, a final fine-tuning comprehensive exercise on all the clusters was performed to guarantee a higher degree of coherence and to correctly label each cluster.[42]

Digital construction management (cluster 12)

26 articles are grouped under this cluster, and it is the most populated amongst those obtained with the LDA technique. The content is focused on the use of digital tools for the better management of construction processes at different levels. Some elements proved to be particularly relevant for the discussion: for instance, the construction industry generates lots of data due to the constant construction activities taking place. The ability to communicate progress information right away and to share it represents key components for successful management of the site and the supply chain network. In this cluster, it is stated that despite the identified problems of information exchange and lack of common standards, improved business relations represent the most urgent area of development in order to better integrate the industrialized and project-based construction. In that sense, BIM helps to take advantage of three-dimensional digital models in design and construction of projects and operational management. This consistent classification of projects can aid researchers and practitioners in many applications such as enhancing the understanding of how agency decisions, like the selection of a project delivery method, impact project performance. Some case studies are presented to show the effect of such a disruptive approach on the sector.

Education and training in support of digital transformation (cluster 1)

13 articles are grouped under this cluster. The use of digital technologies has the potential to significantly change the roles of participants, especially in large projects. Drawing the example from many countries, this cluster focuses on the results of literature review and survey questionnaires on the main challenges that might

[42] For a precise list of the articles grouped in the cluster, please consult Annex I.

represent an obstacle to the organizations' ability to adopt big data and predictive analytics in construction processes. In particular, the attention of some articles is dedicated to the bottlenecks that can derail the successful implementation of BIM technology thus hampering the proper use of digital transformation and subsequently the transition towards a more efficient model in several segments of construction (e.g., waste management).

Fabrication methods, materials and techniques (cluster 3)

13 articles are grouped under this cluster . The content is focused on Digital Fabrication with Concrete (DFC), that also encompasses 3D Concrete Printing (3DCP) and many other methods of production. DFC technologies vary in characteristics, complexity and maturity which hampers the synthesis of research and comparisons of performance. Additive manufacturing (AM) of construction materials has been one of the emerging advanced technologies that aim to minimise the supply chain in the construction industry through autonomous production of building components directly from digital models without human intervention and complicated formworks. However, technical challenges need to be addressed for the industrial implementation of AM, e.g. materials formulation standardization, and interfacial bonding quality between the deposited layers amongst others. The findings from intensive literature review will guide engineers, designers and investors from the construction sector to embrace research gaps and business opportunities. Secondly, process parameters and difficulties in optimization of material mixtures are presented as a guide to civil engineers following the discussion on materials urging the need for development of eco-efficient and environment friendly materials. The environmental issues that remain to be overcome in relation to 3DP concrete is its high-cement content, while the issue in 3DP cob arises from the use of electricity for the 3D printing operation. Examples of early applications of AM technologies in the aerospace, automotive, and healthcare industries might be useful.

BIM for safety and development (cluster 13)

13 articles are grouped under this cluster. The cluster illustrates the fact that construction operations suffer from fragmented structures and loose coupling among project actors. The use of digital technologies and in particular that of BIM can favour higher harmonization among the different phases of the project. Moreover, it is possible to automatically identify potential safety problems resulting from design by integrating BIM (Building Information Modelling) with design safety rules. One study draws from the Loughborough Construction Accident Causation (ConAC) model to create a comprehensive list of accident causes and relates these causes to the identified digital engineering potential, as reflected in the literature. BIM can even assist a greater sustainability that in turn may contribute to eradicating poverty in developing countries.

Digital imagery for construction (cluster 5)

10 articles are grouped under this cluster. The content is focused on the use of digital aerial photogrammetry and laser scanning for the measurement in areas where field mapping and terrestrial photogrammetry or laser scanner surveys cannot be employed because the slope is unsafe, inaccessible, or characterized by a complex geometry with areas not visible from the ground. Some case studies are presented to demonstrate that the adoption of different techniques and technologies linked to digital aerial photogrammetry can accurately help conduct correct measurements and mapping of the environment with results comparable to field measurements. Moreover, the results suggest that data, if correctly analysed and rectified using specific algorithms, could deliver good quality results at a fraction of the cost. Such techniques can also be used for other useful purposes such as experiencing defects in construction, which is particularly interesting.

The use of BIM in digital construction (cluster 7)

10 articles are grouped under this cluster. The cluster focuses on Building Information Modelling (BIM) techniques, that have enabled the construction industry to achieve various benefits. The method of project management and construction has not changed for many decades. One of the main goals of BIM is to provide, based on a 3D model, an accurate information model in a digital format to give different project participants better tools when evaluating different options to support their decisions regarding the project at a given phase. With this in mind, BIM provides a suitable framework to support the decision-makings process by aggregating the necessary information at the right time, and clarifying details and existing conditions; however, the different elements required to make an optimized decision need additional consideration. BIM allows for the implementation of ideas proposed in construction research decades ago that were impractical without a sound digital building information foundation. This is why venture capital has actively sought out startup companies in the 'Construction Tech' sector in recent years.

Emerging technologies in construction (cluster 14)

9 articles are grouped under this cluster. This content is mainly focused on the introduction of emerging digital technologies in the sector. In particular, how the sector is embracing the digital age, the processes involved in the design, construction and how the operation of built assets is more and more influenced by technologies dealing with value-added monitoring of data from sensor networks, management of this data in secure and resilient storage systems underpinned by semantic models, as well as the simulation and optimisation of engineering systems. The implementation of specific technologies such as Digital TWIN in some industries (i.e., quarry) requires a certain number of principles and requirements. Other important technologies prove to be very important for the digitization of the construction industry, the management of a project, from the idea to the use phases, is now based on the Building Information Modelling System (BIM). Advances in distributed

ledger technologies (DLT), also referred to as Blockchain, are being increasingly investigated as one of the constituents in the digital transformation of the construction industry and its response to these challenges. The analysis attempts to give an overview of the current period where disruptive technologies drive the evolutionary adaptation of the construction industry in an historical socio-technological process. In that context, innovation is considered as a succession of transformational waves in an evolutionary process that is currently manifesting as "Industry 4.0" and changing expectations for the construction industry.

Properties of innovative materials (cluster 0)

8 articles are grouped under this cluster. The content is focused mainly on the potential of 3D Construction Printing, that is considered a new and emerging technology capable of revolutionizing construction processes. This technique also looks promising for repair methodologies and to extend service life of concrete structures. Currently the technology is in its early stages of development and many hurdles have yet to be overcome. The main focus of this cluster is on the characteristics of new materials that are useful for the purpose, and in particular on the properties of the of the UHPFRC that might boost the use of 3D-printed components with significant reduction or complete elimination of conventional steel bars. Attention is also being focused on the use of synthetized geopolymers that seems particularly promising.

Safety and risk management (cluster 6)

8 articles are grouped under this cluster. The content is predominantly focused on how organisational measures influence a client's ability to undertake major construction projects in a manner that is conducive to effective project delivery. Empirical research has revealed that authoritarian leaders who block communicative action and the lack of an organizational culture that supports and encourages learning from errors can be determinant for errors in construction. The use of digital

technologies such as BIM can be important for better internal organisation, for a better management of relationships with partners and for the reduction of potential risks such as occupational hazards and injuries. Some studies underline the need to advance the state of knowledge regarding the usefulness and utility of technologies for safety and health management in construction as well as factors that limit and prevent the use of technology in the construction industry.

BIM in project lifecycle management (cluster 4)

7 articles are grouped under this cluster. The content is preponderantly focused on BIM under various perspectives, with a particular tendency to analyse its application and define its ontology in project lifecycle. In that regard, besides having a focus on environmental planning, building design and related management aspects, attention is paid to public procurement requirements and strategies that foresee the use of BIM and other digital technologies. On the same topic, clues are given on how to use information systems to capture dispersed information during a construction project and to translate it into a "lesson learned" database for project management and for the delivery of building project.

New skills and competences (cluster 9)

9 articles are grouped under the current cluster. The content is quite broad, and it covers several subjects. Firstly, it deals with the increasing use of mobile devices at various stages of a construction project which is on the upswing. In fact, construction is witnessing efficient and effective ways of using mobile devices for workers on construction sites. Then, it presents the results of a study aimed at developing a measure for quantifying the readiness of employees with respect to the Industry 4.0 paradigm, analysed though the use of metadata to understand to which extent the skills of profiles 4.0-ready and non-4.0-ready differ. Finally, it also adds other elements on the use of end-user computing and the essential elements of mobile

system and computer vision techniques in construction processes, such as defect inspection, safety monitoring, and performance analysis.

Digital systems for monitoring of construction processes (cluster 2)

6 articles are grouped under this cluster. The content is focused on the impact of the combined use of different digital technologies (i.e., field data capturing technologies, BIM) for automated construction project progress monitoring. In particular, the monitoring of the technical conditions of bridges and descriptions of the authors' remote system for monitoring cracks opening in bridges allowing for the taking of real-time measurements and the automating process of data transmission by means of a wireless communication is described, and details of the processing system and the analysis of the obtained data on the inspection object are provided. Moreover, a conceptual framework is illustrated, and managerial implications are highlighted focusing on requirements, processes and benefits. From this, proposed conceptual framework for development of real-time intelligent observational platform supported by advanced intelligent agents is presented for discussion, in order to identify, report and document "high risk" defects. Building Information Modelling (BIM) serves as a useful tool in facilitating the onsite assembly services (OAS) of prefabricated construction for the benefit of powerful management of physical and functional digital presentations. In this framework, the demands of the stakeholders were analysed; then smart construction objects (SCOs) and smart gateways were defined and designed to collect real-time data throughout the working processes of onsite assembly of prefabricated construction using the radio frequency identification (RFID) technology.

Digitalisation in civil engineering (cluster 11)

5 articles are grouped under this cluster. The content is mainly focused on the use of digital technologies in civil, and in particular in underground constructions (i.e., tunnels) and massive infrastructures such as dams. In particular, the investigation is focused on the use of technology for several purposes such as the measurement and

monitoring of strength and stability of foundation rock, excavation of the dam base and surface treatment, dam shape optimization, safety design guidelines, seismic analysis and design, treatment of a complex foundation, concrete temperature control, and crack prevention. Other techniques such as the check and monitoring of condition of concrete slurry wall, jet-grouting and frozen soil fences by cross-hole sounding method in underground construction" that includes investigation results on the state of massifs of artificial soils established using a set of geophysical acoustic methods is presented. Some case studies of challenging projects were presented: for example, the four diversion tunnels at Jinping II hydropower station represent the deepest underground project yet conducted in China, with an overburden depth of 1500-2000 m and a maximum depth of 2525 m. The tunnel structure was subjected to a maximum external water pressure of 10.22 MPa and the maximum single-point groundwater inflow of 7.3 m3/s. As presented in the summary, the success of the project construction was related to numerous challenging issues such as the stability of the rock mass surrounding the deep tunnels, strong rock-burst prevention and control, and the treatment of high-pressure, large-volume groundwater infiltration.

Data-driven system dynamics (cluster 8)

4 articles are grouped under the current cluster. The content is mainly focused on the necessity to define requirements for data-driven solutions to different scopes. For instance, a model-based rule checking for the planning of construction site layout can be defined through data collection and analysis techniques still done manually. This model can serve as a system for assisting human decision making in tasks such as safe construction sites layout planning. Similarly, for real-time resource tracking, the findings show that both location-based and time-based information of workers can be obtained in real time from the proposed system, but issues of accuracy and coverage need to be considered when defining the data collection plan for each project. The same applies also to leverage information available in different types of product and process models to identify specifications applicable to products existing in a project

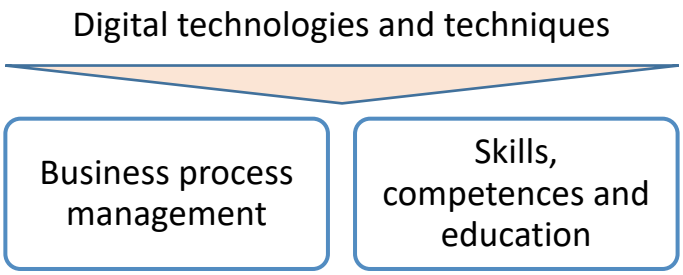
and to extracting the requirements imposed by the specifications applicable to each product.

Blockchain in construction (cluster 10)

Only 2 articles are grouped under the current small cluster. The discussion in these articles is focused on the potential of blockchain technology for the construction sector, that is expected to revolutionize computing in several areas, particularly where centralization was unnatural, and privacy is important. In this context, Blockchain is described as a distributed database that is used to replicate, share, and synchronise data spread across different geographical locations such as multiple sites, countries, or organisations. The main property of blockchain is that there is no central administrator or centralised data storage mechanism. Consensus algorithms govern the peer-to-peer decentralised network. Given, the backward nature of the construction industry regarding digitalisation and its reticence to change, the analyse of the potential impact of Blockchains as a potential disruptive technology, takes on greater importance. One of the two articles in the work analyses the literature on open issues that exist in construction process management and matches them to the capabilities of blockchain.

iv. Final assessment and exploitation of results

It is now time to evaluate the results of the SRL exercise, these results were quite important to determine how to structurer the upcoming chapters. The SLR was a necessary step in detecting, with a certain level of accuracy, the fundamental trends that in one way or another have to do with the digitalisation of the construction sector. While casting a cold eye on the final results, presented above, the clusters can be further organized into three meta-categories that in one way or another represent the most important pillars to be investigated while analysing the phenomenon, as exemplified in the image below.



- **Digital technologies and techniques** [3] [5] [14] [0] [10][43]: this group of clusters describes the digital technologies from the technical point of view, from data technologies to blockchain but also new materials such as innovative geopolymers, that "enable" digital transformation in the construction sector. Case studies are mentioned to prove how these technologies impact the sector on a practically level. This group of clusters is rather rich, and the related subjects have been extensively treated in the engineering reviews, that still represent the majority of the results on digital construction in the SLR.
- **Business process management** [12] [13] [7] [6] [4] [2] [11] [8]: this is the most densely populated meta-cluster, and it contains articles that discuss concrete ways in which digital technologies can be applied in the sector, with a particular focus on the implication on products and processes. In this sense, the adoption of digital technologies entails substantial improvements in business operations which in turn requires that particular attention be given to the management aspects as business models will be significantly impacted by the new digital paradigm. It goes without saying that the economic implication of such a revolutionary process plays a relevant role in the way business will be conducted in the future. However, this meta-cluster is generally more focused on the immediate consequences of the application of digital technologies rather than developing any sort of recommendation for

[43] This numbers between [] refer to the clusters that belong to each meta-category.

digital transformation, which in turns opens the way to further research on the issue. Moreover, although it is an important subject, only limited attention is been given to the importance of data in the new economic scenario. The platform phenomenon that lays at the centre of business model transformation is not extensively explored and requires further investigation.

- **Skills, competencies and education** [1] [9]: this group of clusters focuses on the changes triggered by the digital revolution in the sector in terms of skills, competencies and potential educational/training paths to address the gap that will be caused by the shift to a digital model. It is generally recognized that future curricula need to be strongly focused on the new IT applications, in particularly BIM, in order to reap the benefits of the digital revolution. As testified by the small number of clusters, this topic is only treated by a limited number of articles and it therefore requires further investigation in future research.

The above mentioned results lead me to address what I considered to be some important gaps in the analysis, and in particular to further dig into two of the three meta-clusters (skills, competencies and education and business management) in order to gather more evidence about the changes that are currently affecting the sector. It is then worth mentioning one additional point: besides the areas identified in the SLR, I was also struck by what was missing. There is only very limited or no research on the impact of public policy on the process of digital transformation. Therefore, in the following chapters I'm going to focus first on the impact of digital technologies on the business side. In that sense, I'm going to apply a particular filter to explore the dynamics of digital construction by focusing on those aspects that are typical of the data and platform economy, as described in the introduction. From this perspective, I will enrich my research with the analysis of multiple case studies in order to better investigate the phenomenon.[44] The construction sector represents an extraordinary

[44] Stake, R. E., *Multiple case study analysis*. Guilford press, 2013.

case study, because it is still in its early phases of digital transformation. Then, I will extensively focus on the importance of public policy with a particular eye on the EU strategy and its implication on the sector. The choice of analysing EU public policy on digitalisation is twofold: on the one hand, because of the increasing effort to streamline and harmonize national initiatives on digitalisation, which will be further accelerated in the aftermath of the Covid-19 crisis because of the effect of the Recovery and Resilience Plans that will be adopted in the coming months, where attention on the digital dimension is quite important; secondly, because I had direct access to the EU institutions in order to conduct the interviews and obtain clear insights about the direction the EU policy-makers are heading in, which is the result of an intensive and constant dialogue with stakeholders that are currently pioneering digital transformation in the sector. In that sense, I think that such a privilege is a significant point of strength in order to go "back to the future" and get to the core of the matter.

It is now time to continue the journey in digital construction.

3. Investigating digital construction

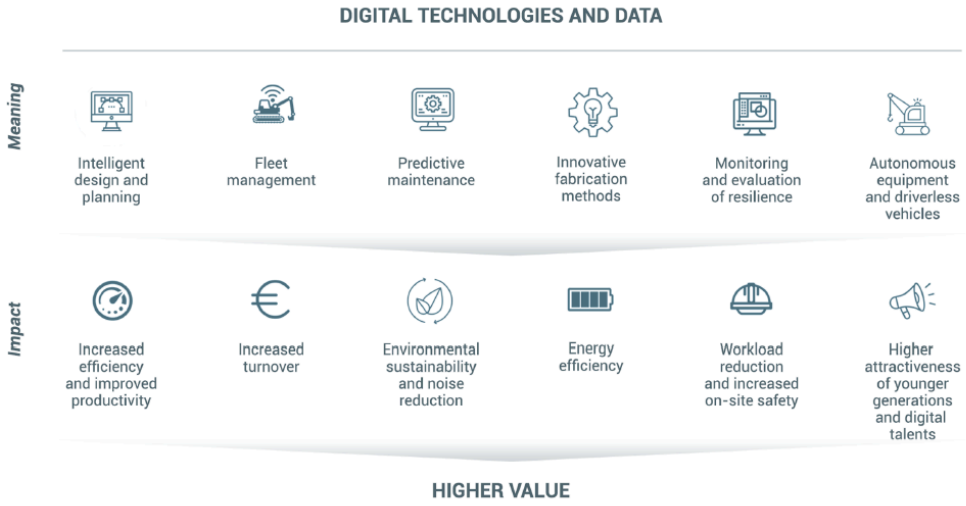
i. Meaning and impact

I'm going to start with a definition that I deem very important in the framework of the current research. What is a correct definition of digitalisation in this context? The answer is far from straightforward. The Gartner dictionary defines it as "the use of digital technologies to change a business model and provide new revenue and value-producing opportunities".[45] This represents a good starting point for further enquiry. However, it opens the way to other questions, in particular in the area of the business model. In fact, the business model is built on several important elements, from the relationship with partners, suppliers and customers to capital investments, and from human resources to value proposition. In fact, if we assume that digitalisation has a direct relationship with the different elements of the business model, it means that it goes far beyond the availability and use of digital technologies as it has to do with the role technologies play in reshaping organizations, processes, products and services as well as improved communication and higher efficiency in managing processes. What is particularly striking is the importance of one common cross-cutting element that connects every single aspect of the discussion: data. In fact, as duly expressed in CECE's report, "the introduction of digital technologies entails rethinking the way companies are structured and have been operating while adopting a more comprehensive approach that foresees new forms of collaboration with other actors along the value chain with the aim of extracting the highest possible value from re-designed digitally-enhanced processes. In this sense, the increased ability to collect, analyse, integrate and use data derived from several sources (i.e. geographic information systems, cyber-physical systems on construction equipment, weather data, drone aerial photography systems, mobile devices and tablets) contributes to a higher level of transparency between actors thus leading to a substantial improvement in the management of construction sites thanks to closer collaboration. In summary,

[45] Gartner Glossary: https://www.gartner.com/en/information-technology/glossary/digitalization

we can further elaborate Gartner IT definition and affirm that digitalisation means using enabling digital technologies to "gain insights and leveraging the power of information that stems from the collection, analysis and management of data to provide new solutions with a higher value added."[46]

In general, digital technologies can be employed for a plethora of different purposes and can generate a significant impact on a variety of different aspects, as exemplified in the image below.



Source: ID Consulting & S.I.RI.O.

Some technologies are considered of paramount importance for the digitalisation of the sector and for the realization of the abovementioned tasks: Internet of Things (IoT), additive manufacturing (3D printing), drones, GIS, BIM (Building Information Modelling), Virtual and Augmented reality, Big Data, robotics, and Artificial Intelligence, Blockchain.[47]

[46] *Digitalising the construction sector – Unleashing the potential of data with a value chain approach*, CECE, January 2019, page 11.

[47] For a more detailed picture of the relationship between technologies and the tasks mentioned in the image, please refer to the table of CECE's research at page 12.

While showing clear numbers on the economic impact of digitalisation on the sector is far from an easy task[48], most of the protagonists of the sector tend to agree that it could bring significant positive changes. According to the Boston Consulting Group, within 10 years, full-scale digitization could help the industry save an estimated 12-20%, equal to between $1 trillion and $1.7 trillion annually at global level.[49]

In particular, it can contribute to an improvement in productivity levels as well as an increase performance thus leading to higher economic margins and competitiveness. In fact, digital technologies can generate gains in terms of cost savings, improved quality, and novel services. In addition, the adoption of new technologies can become an element in attracting a new labour force as well as contribute to an enhanced environmental sustainability and safety of workers (i.e., through the automation of more dangerous tasks).

Among the most important drivers of digitalisation in the sector, is probably the need to cut costs and increase productivity. It is accepted that a big difference exists between large, small and medium players: the former are more aware of the benefits of digital technologies and have the wherewithal (both in terms of financial and human resources) to shoulder the costs of digital transformation and to push for a higher integration of digital technologies in business processes.[50] This is particularly important in complex building ecosystems that require a greater level of integration among all the players such as tier 1 and sometimes tier 2 levels. The potential results in terms of higher resource efficiency leads inexorably to potentially higher margins. Moreover, the use of digital technologies means that highly customized products and services with a higher added value can be offered, thus increasing customer loyalty. Large companies can trigger a trickle-down effect and promote greater digitalisation in the sector because they are aware that the benefits of some technologies (i.e. BIM) can be fully seized only if all the companies across the value chain become partially

[48] Interviewees are skeptical about giving precise numbers because they deem difficult to isolate the pure digital factor from other elements of the ecosystem in which companies operate such as market development, skill factor, institutions, etc.

[49] *6 ways the construction industry can build for the future,* Boston Consulting Group, World Economic Forum, 2018.

[50] ECSO, *Digitalisation in the construction sector*, Draft Analytical Report, April 2021.

or fully digitalized. In this sense, they are interested in offering small players customised assistance and training to speed up the process.

While large players have an important role to play, small players and in particular start-ups deserve particular attention for the digitalisation of the sector. In particular, "construction start-ups fill a gap by pursuing opportunities associated with radical innovations, and translate it in a way that makes financial and technical sense in the construction sector. These start-ups provide focused solutions around a single technology, solving specific but sector applicable issues, mainly around BIM, additive manufacturing and drones" This in turn can explain the increase in Venture Capital in the sector, that went "**from EUR 43 million in 2012 to EUR 1,199 million in 2018 (with a record increase of 177% between 2017 and 2018)**. However, these investments are largely concentrated in the US and China, with European digital start-ups accounting for only 4% of global VC funding in digital construction start-ups in 2017 [in particular] France, the United Kingdom, Germany, and Sweden attract most of these investments.[51] With this in mind, large companies decide to create "parallel start-ups" so as to speed up innovation processes by tailoring their new and innovative solutions to the mother company. In his book "The New Oil", Arent Van't Spijker describes the parallel start-up phenomenon as a start-up created by a company to develop products in different markets. This start-up is managed and operates independently but, in a way, that ensure that the "common interest between the parent company and the start-up is managed for maximum benefit". The parallel start-up can leverage key resources (data) belonging to the parent company, and it has proven to "leverage innovative business models from existing companies".[52]

The image below shows that by filling the gap vis-à-vis the trend, the manufacturing sector would already represent a significant improvement for the sector.

[51] ECSO, *Digitalisation in the construction sector*, Draft Analytical Report, April 2021, page 93.
[52] *Digitalising the construction sector – Unleashing the potential of data with a value chain approach*, CECE, January 2019, page 20.

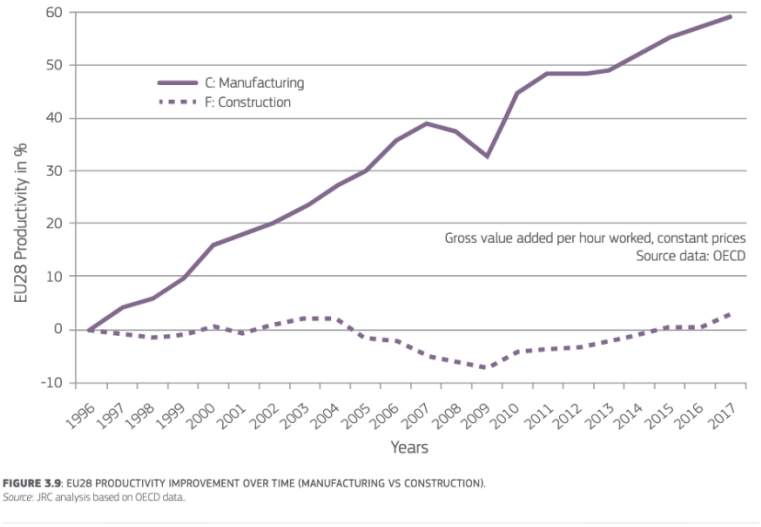


FIGURE 3.9: EU28 PRODUCTIVITY IMPROVEMENT OVER TIME (MANUFACTURING VS CONSTRUCTION).
Source: JRC analysis based on OECD data.

Source: JRC analysis based on OECD data

In order for that to happen, as mentioned in the JRC policy report "The digitalisation of the whole process is central to the future of Construction: from the initial investment and call for tenders to the design and planning phase, the construction phase (procurement and supply chain, construction site management) and, after completion, the OM&R phase (asset, property, and facility management)" [53]. In that regard, it is worth adding that digitalisation is not only limited to the digital integration of processes and tasks, but also of the actors of the entire value chain, which in turn will be completely revolutionized in the years to come. I will illustrate point when dealing with the functions and characteristics of data platforms in the next section.

It goes without saying that a wide number of barriers still limit a fast and smooth transition to a digital model, from the high cost of digital transition vis-à-vis the lack of fast and measurable returns, to the lack of adequate skills and competences in the organisations, from a cultural and procedural resistance to change to the absence of commonly recognized standards and low interoperability.

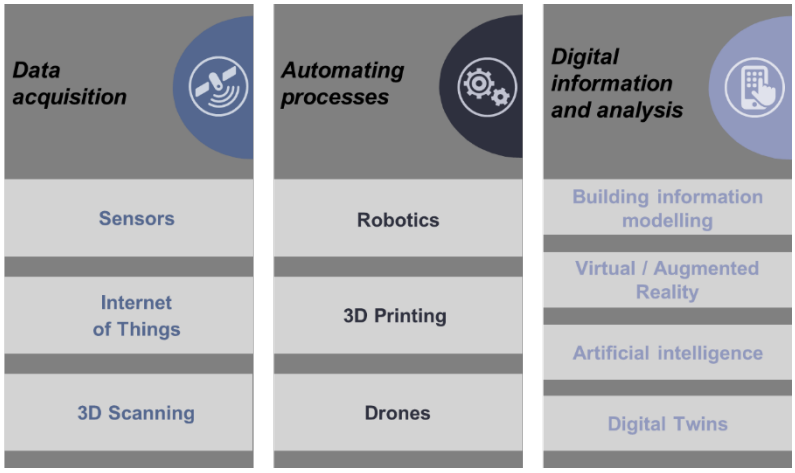
[53] *Digital Transformation in Transport, Construction, Energy, Government and Public Administration*, JRC Policy Report, January 2019, page 17.

ii. Technologies, data and new business models

Following the above general introduction, I would like to now turn my attention to a key element of digital transformation, namely the relationship between digital technologies, and in particular data, and new business models. This section is intended to provide meaningful insights about the changes occurring in the sector and to understand what digitalisation means in terms of business management, with a \sector is very fragmented, and it is characterized by the presence of a significant number of stakeholders, contractors, suppliers and sub-suppliers with intertwined relationships. As testified by other sectors, digitalisation might bring substantial benefits from different points of view. This is particularly relevant for the sector for at least two reasons: on the one hand, it might help boost productivity, that has been stagnant for a long time as confirmed by a variety of different studies.[54] Secondly, thanks to data science, new ways to investigate and make sense of complexity will emerge opening the way for new forms of collaboration among parties all along the value chain to provide targeted and innovative solutions reducing the level of fragmentation while bringing a new wave of modernisation. I will come back to this last point while investigating some case studies.

The adoption of digital technologies in the sector has several major implications. As mentioned in the recent ECSO Draft Analytical Report[55], the technologies are organised in three categories: data acquisition, automating processes, and digital information and analysis (see image below).

[54] As an example, both McKinsey and The Economist have been extensively investigating the problem of low productivity in the sector in a number of studies and articles easily accessible on the web.
[55] ECSO, *Digitalisation in the construction sector*, Draft Analytical Report, April 2021, page 16.



Source: ESCO Draft Analytical Report (2021)

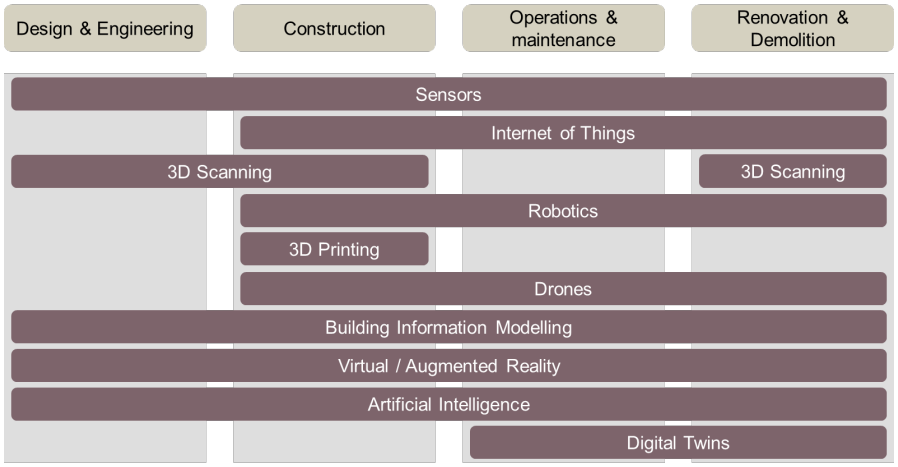
- **Data acquisition refers to the unprecedent availability of massive amounts of data from sensors, scanners and connected devices** (IoT) concerning all aspects of the construction, from geo-localisation to humidity levels, from energy usages to air quality, from video recordings to seismic measurements. […]
- **Automation processes** through the adoption of robots, additive manufacturing, drones and other machineries are key to the development and modernisation of the sector. By automating certain activities, not only the final quality of the project increases, but workers are also less exposed to risks and new materials and techniques can be deployed. […]
- **Considering the two categories just mentioned, digital information and analysis is, therefore, crucial for connecting all innovative technologies in this sector and processing the available data**, thus leading to significant improvements and transformations in the way the work is done. In fact, the added value of having real-time information, precise measurements, and historical stock-taking databases will be increasingly important and essential for the sustainability and competitiveness of the sector.[56]

[56] *Ibid*.

IoT for instance is an enabling technology for fleet management, predictive maintenance of equipment as well as for better monitoring of energy consumption and the machine performance, opening the way for better and improved solutions. They can shorten the distance between producers and consumers: data analysis opens new ways for a better interpretation of the market's needs and expectations, allowing for a higher level of customisation of products and services to better serve emerging requests. As an example, the increase in post-sale services based on the use of data technologies favours a constant interaction with the customer, contributing to building of higher trust amongst and towards producers. They enhance the connection of processes not only at jobsite level but all along the value chain, touching every aspect of construction from raw material production to logistics, from operation processes to building maintenance, up to demolition and material recycling. The growing use of cloud platforms where data coming from multiples sources is stored and potentially analysed opens "the way for the creation of new integrated products, services and support solutions across all phases of a project" where higher levels of circularity can be expected.

On the one hand, all these technologies are highly interconnected and on the other can be applied not only throughout all phases of the construction process, but also at any point of the building lifecycle (see figure below) even if for the time being they tend to used only in specific cases as it is easier and more cost-effective to integrate them from the beginning and structure the project based on their use, rather than undertaking additional investments to implement them in already-existing buildings[57].

[57] *Ibid,* page 17.



Source: ESCO Draft Analytical Report (2021)

Again, one cross-cutting trend sits at the centre of the entire discussion: data. The massive increase in data is leading to the rise of disruptive and innovative business models in the sector. In fact, companies are increasingly aware that "having access to such data will be crucial in improving overall construction processes"[58], products and in improving market positioning vis-à-vis potential competitors. But while collecting data is important, "even more important is extracting new insights and value from the data, mainly through the use of machine learning algorithms and artificial intelligence. Access to data has become a key issue in promoting AI as a new phase in digital transformation."[59] It comes as no surprise that telematics and IT industries show more interest in the sector as it offers greater potential both in terms of size and given the gap that still needs to be filled to reach full maturity, giving raising to some concern amongst traditional players. I will come back to this point while discussing the challenges linked to data sharing, more in detail.

In particular, the *servitization* trend is gaining momentum. *Servitization* can be defined as "the gradual shift from product-centred value propositions to complex

[58] *Digitalising the construction sector – Unleashing the potential of data with a value chain approach*, CECE, January 2019, page 11.
[59] *Digital Transformation in Transport, Construction, Energy, Government and Public Administration*, JRC Policy Report, January 2019, page 39.

product-service systems offerings".[60] The combination of products with services means delivering highly customised solutions based on the outcome that the client wants to achieve: "selling 'holes' rather than drills; the customer wants to make a hole; the use, condition, features and performance of the drill is just a way of achieving that outcome, but isn't what the customer wants to concern themselves with"[61]. Following this logic, clients "do not just pay for the machine but rather for the complete solution to their problem". They "purchase a product and along with that receive services such as maintenance and support to reach their ultimate goal."[62] It is worth noticing that *servitization* is strongly outcome driven. As mentioned in CECE's report, adopting a "*servitized* outcome-based business model means monetizing services that can be offered to the client and leveraging the potential of data analysis to succeed. As an example, rental companies can leverage on data gathered from the usage of machines (i.e., location, idle time, energy efficiency, kind of environment) to move to a pay per use/per outcome model for a specific task to be performed on-site – such as moving a specific amount of earth on the jobsite."[63] But in order for that to happen, the data must firstly be available and accessible. Sets of data generated in one specific segment of the construction sector can also be highly beneficial to other sectors all along the value chain. As shown in the SmartSite project, data coming from asphalt mixing plants and vehicles transporting asphalt are particularly useful for road builders in order to reduce logistical downtime and improve the quality of road compaction.[64] Similarly, data sharing between a Skanska and Volvo was at the centre of an ambitious and successful project aimed at

[60] Mastrogiacomo, Barravecchia, Franceschini, *Definition of a conceptual scale of servitization: Proposal and preliminary results,* CIRP Journal of Manufacturing Science and Technology 29 (Part B): 141-156, May 2020.
[61] T. Baines, *Towards a Common Definition of Servitization,* 2016) Aston Business School.
[62] *Digitalising the construction sector – Unleashing the potential of data with a value chain approach*, CECE, January 2019, page 18.
[63] *Digitalising the construction sector – Unleashing the potential of data with a value chain approach*, CECE, January 2019, page 18.
[64] Juenze, Teizer, Mueller, Bickle, *SmartSite: Intelligent and autonomous environments, machinery, and processes to realize smart road construction projects,* Automation in Construction, Volume 71, Part 1, November 2016, pages 21-44.

propelling the quarry industry towards a "zero emissions" target.[65] These two examples show that "the ecosystem approach is the key to exploiting the benefits of data analysis and providing innovative solutions to improve processes and operations onsite".[66] In practice, that means collecting, integrating and crossing large volumes of data on processes and operations onsite to better identify potential bottlenecks so as to provide new targeted solutions.

Technically speaking, this is possible thanks to the growing introduction of data platforms where data from multiple sources are gathered. It is worth noticing that data platforms can serve several purposes, such as facilitating communication in the different phases of the project, from its inception to completion, among the different partners involved in the same construction project. They can also be conceived and designed as a marketplace where different players can easily buy and sell all kinds of solutions, acting as an important matchmaking environment. In addition, data platforms enable data exchange among the different parties. This data can be further analysed and exploited with the use of AI technologies thus contributing to the creation of new and innovative data-driven solutions to be monetized.

The role and the characteristics of data platforms in the construction sector are not different from those of other sectors. According to professor Žiga Turk from the University of Ljubljana, data platforms are particularly useful to reuse/replicate solutions developed and systematized in the framework of a construction project into a multitude of other projects in the sector, thereby favouring economies of scale. This might explain the current race among different software houses such as Trimble, Leica, Topcon and Trackunit, just to mention a few of the main players active in the sector, to develop proprietary platforms and new solutions to be applied in several contexts. Generally speaking, data platforms act on the one hand as operating systems such as iOS or Android where a main package of elements such as architecture, standards and other tools are established in order to host third-party applications. At

[65] For further information on this project, see: https://www.volvoce.com/global/en/this-is-volvo-ce/what-we-believe-in/innovation/electric-site/

[66] *Digitalising the construction sector – Unleashing the potential of data with a value chain approach*, CECE, January 2019, page 20.

the same time platforms can also act as a marketplace by operating as digital matchmakers among the different users for commercial purposes, namely buying-selling different products and services and/or retrieving the expertise necessary for construction projects.

However, the spread of data platforms comes with certain risks as well. In particular, the current trend might lead to the rise of powerful corporate conglomerates who display monopolistic behaviour and predatory practices following the experience of other well-known players like Facebook, Amazon, Uber, Airbnb etc. According to Professor Turk, in order to mitigate such risk, regulation shall be envisaged to prevent vertical integration of platform and applications.[67] It comes as no surprise that this particular element is also at the centre of the debate around the future governance of the digital industrial platform for the construction sector that is the object of the EU-funded project DigiPLACE.[68]

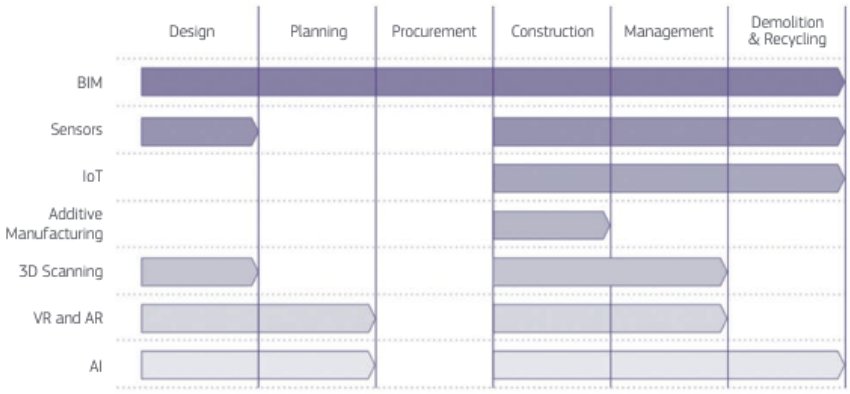
If we focus our attention on data sharing, Building Information Modelling (BIM) is considered to be one the most promising technologies as it m potentially provide new solutions by enabling extensive data sharing at different levels and significant savings – currently estimated around 15-20%. According to the EU BIM Task Group, BIM is "a digital form of construction and asset operations" that "brings together technology, process improvements and digital information to radically improve client and project outcomes and asset operations. BIM is a strategic enabler for improving decision making for both buildings and public infrastructure assets across the whole lifecycle. It applies to new build projects, and crucially, BIM supports the renovation, refurbishment and maintenance of the built environment – the largest share of the sector."[69] According to the JRC, "BIM is already being adopted by major clients and developers, construction companies, and design firms due to it having the advantage

[67] In this context it is worth remembering the example of then 2001 antitrust law case *United States v. Microsoft Corporation* 253 F.3d 34. Microsoft was accused of illegally maintaining its monopoly position primarily because of the restrictions put on the abilities of PC manufacturers and users to uninstall Internet Explorer that damaged competitors, in this case Netscape.

[68] DigiPLACE project is described in chapter 4 iii a).

[69] *Handbook for the introduction of Building Information Modelling by the European Public Sector*, EU BIM Task Group, page 4.

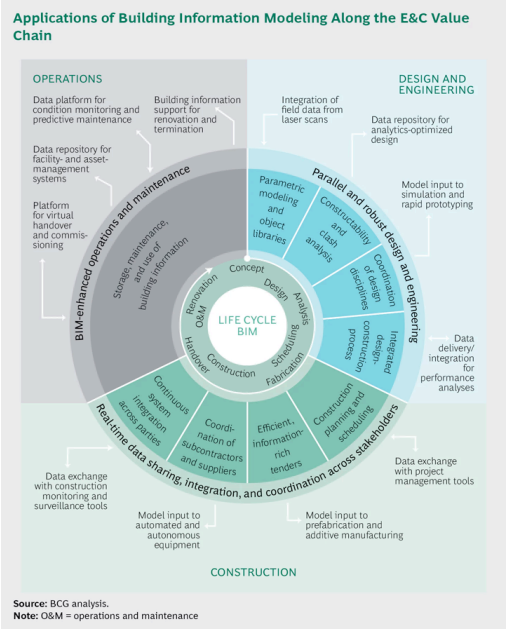
of allowing interdisciplinary collaboration and smooth sharing of data, but there is still the need to complete standardization[70] (which is waiting for the CEN 442 work to be completed) and full adoption throughout the construction life cycle."[71]



Source: JRC

BIM can potentially be applied to every step of the lifecycle including operations and management of built assets after delivery and it is therefore often a synonym for digitalisation in construction. In addition, BIM can enable collaboration between stakeholders in and across all phases, resulting in better integration and communication as underlined by the analysis of the Boston Consulting Group. The same study states that "full-scale digitalization in non-residential construction will lead to annual global cost savings of $0.7 trillion to $1.2 trillion (13% to 21%) in the engineering and construction phases and $0.3 trillion to $0.5 trillion (10% to 17%) in the operations phase." [72]

[70] For further information about the standardization process, please refer to the next section.
[71] *Digital Transformation in Transport, Construction, Energy, Government and Public Administration*, JRC Policy Report, January 2019, page 112.
[72] *The Transformative Power of Building Information Modeling*, Castagnino, Rothballer, Renz, and Filitz, March 2018, Boston Consulting Group https://www.bcg.com/publications/2016/engineered-products-infrastructure-digital-transformative-power-building-information-modeling



Source: Boston Consulting Group

In summary, in order to fully benefit from the potential of the digital revolution data must first and foremost be shared. Better data integration among all of the actors in the construction processes, from designers to suppliers, from OEMs to contractors can lead to higher efficiency thereby contributing to higher productivity levels. In fact, successful examples of digital transformation show an increasing level of collaboration among the parties in the construction sector and beyond, which entails a higher level of trust. Several case studies show that new forms of collaboration are increasingly emerging both among OEMs, rental companies, and contractors as well as IT companies that provide the IT technology, causing disruptive effects in the entire value chain. Thanks to the new opportunities offered by digital technologies, business models are rapidly changing and boundaries among the different players are tending to blurry. In fact, because of the *servitization* trend, companies can now chase new and profitable opportunities that could entail substantial shifts in the market approach and business models. As an example, thanks to better insights into the behaviour of their customers enhanced by data technologies, OEMs might increase their rental services, offering more flexible and customized solutions. At the same

time, rental companies could find new streams of revenue by focusing on logistics services that are a direct and enhanced evolution of their current know-how (the ability to know where and when machines are could be made available based on the analysis of customers' needs).

Data sharing however is far from an easy task for several reasons.

While large companies do not fear competition from IT players because they are confident that their capital-intensive nature and know-how protects them from potential takeovers, some others – especially medium and small sized enterprises – are still reluctant to share data as "they fear the losing their know-how to the advantage of other players and of being commoditized"[73] and they even perceive IT giants as potential competitors who might threaten their very existence if data is not adequately protected. Considering that SMEs represent the vast majority of the players in the sector, this might represent an important obstacle to a smooth and fast digital transformation. We should add that the SMEs often have very low margins and lack the financial means to invest in specialized IT innovation, impeding a fast adoption of IT tools and, de facto, slowing down the digital transformation of the sector.

Large companies, on the other hand, already make wide use of IT tools, procedures, designs and planning, and have a growing interest in partnering with IT companies "to integrate high quality components in machines and in the jobsite, improving their ability to create new data-driven services while having access to a wide array of data that can prove useful in improving their operational capacity. Such partnerships might also lead to the design of new products/services that are a mixture of various solutions."[74] However, considering the complexity and fragmentation of the construction value chain, the differences in digital maturity between small, medium and large players can hinder the implementation of fully digitalized construction sites. If we add that the IT sector is also characterized by a few giant platforms that control

[73] *Ibid.*

[74] *Digitalising the construction sector – Unleashing the potential of data with a value chain approach*, CECE, January 2019, page 21.

a large share of the market, concern is mounting around the risk that they might impose unfair conditions on other market participants because of their dominant positions.[75] Moreover, the increasing presence of "cloud-based solutions, where data is transferred and stored on remote servers often located outside the EU and controlled by non -EU entities, has raised concerns over the legitimacy and benefit of these IT architectures, particularly considering the increasing adoption of such IT systems."[76]

Nevertheless, new forms of data sharing models are emerging, such as the so-called "banking model" where the data originator (e.g., a contractor or a rental company) decides to grant access to its own data to a third party (e.g., OEM or telematics company) on the basis of a clear contract that establishes what data is shared and for what purpose. In exchange, the data originator receives a sort of "interest" in the form of data-driven services stemming from the results of data analysis (this is a clear example of *servitization*). Or, following the example of other sectors, the members of the value chain can opt for voluntary mechanisms of data sharing such as the Code of Conduct on Agricultural Data Sharing by Contractual Arrangement agreed by Copa and Cogeca, CEMA, Fertilizers Europe, CEETTAR, CEJA, ECPA, EFFAB, FEFAC, ESA signed on April 23rd, 2018, in Brussels that contains "a series of non-binding principles on the rights and obligations of accessing, (re)using and sharing data that are reflected in contractual agreements between the parties" with specific guidelines on "data ownership, data access, control and portability, data protection and transparency, privacy and security, liability and intellectual property rights."[77] It is interesting to note that as in the case of the banking model, here also the data originators have a leading role and they have the final word on the way their data is shared, with whom and for what purposes.

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[75] *Digital Transformationin Transport, Construction, Energy, Government and Public Administration*, JRC Policy Report, January 2019, page 39.
[76] *Ibid.* page 123.
[77] *Digitalising the construction sector – Unleashing the potential of data with a value chain approach*, CECE, January 2019, page 40.

The European Commission pays particular attention to this subject and it is currently acting at different levels to further accelerate data sharing among parties in order to boost the data economy in the EU through a mix of regulatory and financial measures. This subject will be briefly discussed in the next section and it will be treated extensively in chapter 3.

iii. Public policy, skills, and organisations

The success and the speed of digital transformation in the sector goes far beyond the efforts of the private actors as it depends also on other elements in the "ecosystem". In particular, the speed and effectiveness of digital transformation is highly influenced by the role of the public sector, the nature and culture of organisations, and the skills and competences of the workforce. All of these factors are closely intertwined and influence one another, as I will discuss in the next section.
Currently, governments are the most important clients of the construction industry. According to the World Economic Forum's estimates, "government procurement accounts for a major share of total construction expenditure worldwide: for example, 31% in the United Kingdom, 44% in Germany and a staggering 57% in the United States."[78] Therefore, the public sector can actively contribute to drive industry change through new forms of public procurement that stimulate the adoption of digital technologies in new building projects. Some efforts in that direction have already been made, as testified by the EU Directive 2014/24/UE that encourages the use of BIM in public procurement practices across Europe.
In that regard, there is a second important aspect that is worth mentioning that could be highly beneficial to both the private and the public sector. The wide and capillary adoption of digital technologies such as BIM, IoT, digital twin, etc. and cloud platforms will lead to higher transparency allowing for a better monitoring of construction phases at every level and (potentially) greater trust between parties. This

[78] World Economic Forum, *Shaping the future of construction – A breakthrough in mindset and technology*, May 2016, page 47.

might in turn help identify and neutralize potential corruption practices that represent a cumbersome problem for the sector as it substantially increases procurement costs by an estimated €1.3-1.9 according to a study prepared by the European Commission.[79]

One crucial aspect for digitalisation to thrive is standardisation. The adoption of proprietary systems and/or guidelines tend to represent an entry barrier, limiting competitiveness in the market. This is why some scholars advocate the adoption of open data standards in order to improve the spread of digital technologies and, in particular, data exchange in the sector while avoiding potentially monopolistic behaviours. Standardisation and legal discussions driven by the world-wide standards organisations exist to tackle elements such as data interoperability, liability issues concerning the use of data, ownership and intellectual property rights and rights and responsibilities in general. Within the framework of this research, it is worth mentioning the three following examples:

- ISO/TS15143-3 Earth-moving machinery and mobile road construction machinery – worksite data exchange: "this standard defines the communication records to be used when requesting data from the provider's server in which the data is stored and the responses from the server that must contain the specified data to conduct the analysis on the machine's wellbeing and performance, enabling the equipment owner to manage a mixed fleet."[80]
- ISO/TC 59/SC13 international standardization of information through the whole life cycle of buildings and infrastructure across the built environment to enable interoperability of information; to deliver a structured set of standards, specifications, and reports to define, describe, exchange, monitor, record and securely handle information, semantics and processes, with links to geospatial and

[79] *Ibid.*, quoting a 2013 study realized by PwC and Ecorys that analyzed 192 public procurement projects in eitgh EU countries,

[80] *Digitalising the construction sector – Unleashing the potential of data with a value chain approach*, CECE, January 2019, page 31

other related built environment information; to enable object-related digital information exchange.[81]

- CEN Technical Committee 442 on BIM: "a structured set of standards, specifications and reports which specify methodologies to define, describe, exchange, monitor, record and securely handle asset data, semantics and processes with links to geospatial and other external data […] The aim is to help the construction sector to be more efficient and sustainable by enabling a smooth and comprehensive information exchange and sharing between partners in the value chain."[82]

As already anticipated in the previous section, another fundamental important of the discussion concerns the legal issues concerning the ownership and access to data. As underlined in the JRC technical report, "there is currently no legal or statutory title providing for ownership of data as such (either from traditional property rights or as intellectual property since data per se is not copyright able or patentable subject matter) even though under certain circumstances data is protected by the database's *sui generis* (Directive 96/9/EC) right or by the trade secrets directive (Directive (EU) 2016/943) provided certain conditions are met." As a result, "data access use and sharing are regulated at the contractual level on the basis of a *de facto* (rather than legal) ownership" where "contract is king".[83] While the issue of ownership of data tends to be rather theoretical and might lead to controversies among those with differing views (i.e., regarding the need to introduce IP on data), there's an increasing push for the introduction of data access because of its very practical implications. In that regard, the recent regulatory initiatives of the European Commission in support of a cross-sectoral governance framework for data access and use, are aimed at creating "frameworks that shape the context, allowing lively, dynamic and vivid

[81] Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM), also see: https://www.iso.org/committee/49180.html
[82] JRC Technical Reports, *Building Information Modelling (BIM) standardization*, 2017, for detailed information see:
https://publications.jrc.ec.europa.eu/repository/bitstream/JRC109656/bim.standardization_1.pdf
[83] *Ibid*, page 31.

ecosystems to develop" thereby favouring the transformation towards a data-agile economy.[84]

It is worth remembering that Commission's Staff Working Document that accompanied the Communication *Towards a common European data space* published in 2018 already mentioned "a series of key principles to be considered so as to make data interactions in business-to-business and business-to-government situations a success for all the parties involved."[85]

Data regulation goes hand in hand with competition law as monopolistic behaviours might hinder the fair and correct functioning of the Single Market. In particular, in the last years a certain number of giant online platforms emerged, raising some concerns among policymakers. Because of their dominant positions, these platforms have the power to impose unfair conditions on market participants (especially SME) and they are increasingly subject to scrutiny by regulators because of several reasons, from the lack of transparency in data collection and exploitation up to the nature and purpose of their search and recommendation algorithms.[86]

In any case, as mentioned in CECE's study, a significant number of players from the private sector is increasingly aware of the importance of finding new and efficient governance models for data sharing and data management. Therefore, they advocate that the public sector play an active role in facilitating and steering the discussion on digitalisation among different parties also suggesting new forms of collaborations between the public and the private sector such as public-private partnerships (PPPs)[87]

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[84] COM (2020)66 final, *A European strategy for data*, page 12. For further information, please check chapter 2, ii, a).

[85] SWD(2018) 125 final, *Guidance on sharing private sector data in the European data economy*, page 2.

[86] *Digital Transformation in Transport, Construction, Energy, Government and Public Administration*, JRC Policy Report, January 2019, page 39.

[87] According the EU Glossary, Public-private partnerships (PPPs) are long-term contracts between two units, whereby one unit acquires or builds an asset or set of assets, operates it for a period and then hands the asset over to a second unit. Such arrangements are usually between a private enterprise and government but other combinations are possible, with a public corporation as either party or a private non-profit institution as the second party (Article 15.41 of Regulation (EU) No 549/2013). The European Commission has been investing heavily in Public Private Partnerships (PPPs) to enable a long-term, strategic approach to research and innovation and reduce uncertainties by allowing for long-term commitments (https://ec.europa.eu/digital-single-market/en/public-private-partnerships)

or Joint Undertakings[88], to favour a constant dialogue that can lead to more effective legislative actions by a constant fine-tuning of the policy agenda as well as to the introduction of funding schemes to facilitate digital change.[89]

These forms of collaboration look particularly promising because they allow for the pooling of significant resources both from the public and the private sector, generating greater impact on the economy thorough a multiplier effect. Financial support is particularly important for SMEs whose upfront costs for digitalisation, whose results are not always clear, tends to be rather onerous in proportion of their turnover. In addition, other forms of public support such as tax breaks and fiscal measures, incentive schemes and/or grants in favour of research and innovation as well as more robust investments in digital education are considered to be effective tools to trigger change in the sector.

One final aspect is particularly relevant for digitalisation in the sector to happen: skills and competences. There is significant consensus among scholars on the disruptive effects of digital technologies on the job market. According to a recent Eurofound study[90], three major trends seem to affect work and employment:

- The automation of work, meaning the increasing use of robots that will gradually replace human labour in building processes, especially the most repetitive and heavy ones (e.g., bricklaying).
- The digitisation of processes, meaning the extensive use of sensors and IoT technologies that translate physical processes into digital ones, substantial improvements will be possible thanks to the increasing information on construction processes.

[88] For further information on Joint Undertakings, please visit the following website: https://eur-lex.europa.eu/summary/glossary/joint_undertaking.html

[89] *Digitalising the construction sector – Unleashing the potential of data with a value chain approach*, CECE, January 2019, page 30. More detailed information on the EU funding opportunities is extensively presented in section iii of chapter 3.

[90] *What do Europeans do at work? A task-based analysis: European Jobs Monitor 2016*. Publications Office of the European Union. Luxembourg.

- the coordination of platforms, meaning the use of digital platforms to coordinate the work of the different actors all along the value chain and on site, which will favour a better allocation of human and physical resources in every phase of the process.

While speaking of the construction sector, the problem of job-replacement by machines is probably mitigated in the construction sector. In the EU, several trends such as ageing population, low birth rates and shrinking proportion of the working-age population translate into greater scarcity of workers in the sector. According to the European Centre for the Development of Vocational Training (CEDEFOP), about 1 million new and replacement workers will be needed by 2025. Additionally, the skills needed in construction are likely to change to meet the demands for green and energy-efficient buildings[91] as well as digitalisation. Moreover, the issue is exacerbated by the low level of attractiveness among younger people including women and dire security concerns (i.e., high accident rates, as mentioned above).
In addition, we assume that "digitalisation leads to a decline in jobs that are mainly made up of routine tasks (manual or cognitive routines) and an increase in the number of jobs that have a lot of cognitive non-routine tasks"[92]. However, "in the EU-28 level in the construction sector more than 50% of those employed are crafts and trade workers and this share reaches almost 70% in the case of migrant workers"[93] (2016 data) meaning mainly building frame workers and building finishers with a very high RTI index, therefore the potential risk of being automated is partially reduced. At the same time, low level and elementary occupations (that according to the JRC Policy report account for 8% of the workforce and it is represented prevalently by EU and non-EU migrant workers) suffers from a very high automation potential risk. Chances

[91] As mentioned in the document *A Blueprint for Sectoral Cooperation on Skills (Wave II*) "according to an evaluation of the Build Up Skills (BUS) initiative, 3-4 million workers will require training on energy efficiency alone. Plus, a digital transformation will be essential in delivering more efficient buildings and construction processes."
[92] *Digital Transformation in Transport, Construction, Energy, Government and Public Administration*, JRC Policy Report, January 2019, page 140.
[93] *Ibid*. page 141.

of improvements are even more reduced if we think that these categories of workers who have "lesser probability of receiving professional training and a greater likelihood of being employed on a fixed-term contract than nationals"[94] thus making them that much more vulnerable to economic (i.e. COVID-19 crisis) and technological shocks.[95]

However, also medium level occupations will be impacted by the digitalisation wave as the use of driver-assistance systems and self-driving machines might oust some skilled wheel loaders and excavator operators from the job-market. These jobs run the risk of being increasingly "replaced by higher level positions (i.e., software developers, app programmers) where employees will be responsible for working out innovative solutions for the connected jobsite."[96]

This said, digitalisation represents an important element in the improvement of the image of the sector and increases the attractiveness for both women and men. A greater level of involvement of younger generations will be increasingly necessary as it will potentially boost digital transformation in the sector, especially if we consider that older generations – who still constitute the bulk of the workforce in the sector – are more reticent about embracing change. At the same time, the experience and the know-how of older generations still constitute an important element of competitiveness in the sector – especially among capital intensive industries – and efforts should be made to find a synthesis between older methods and the paradigms of the new digital society.

If we shift the focus from the role of the individuals to the role of organisations, we can say that "companies will increasingly need to acquire digital skills because of growing need of collecting, analysing and managing data" while the adoption of digital technologies "will oblige workers to have the skills to use tablets and other smart devices that will make the use of machines and the monitoring of processes and operations on the

[94] *Ibid*. page 143.

[95] According to the same study, migrants working in the construction sectors are 3.5 times more likely to be employed in jobs that have high automation potential compared to non-migrant workers. This likelihood is 2.6 times for EU migrants.

[96] *Digitalising the construction sector – Unleashing the potential of data with a value chain approach*, CECE, January 2019, page 37.

jobsite much easier." This in turn translates in the need to "rethink education and training so as to serve the objective of equipping current and future employees with the necessary digital and technical skills"[97] to face the challenges of digital transformation. It should come as no surprise that an increasing number of companies advocate for closer forms of cooperation between the private sector and the educational system, in particular VET schools and universities so as to design new training programs for current and future employees.

In this context, there is an additional element worth mentioning. In general, digital transformation is far from an easy task. According to recent research carried out by the Boston Consulting Group, 70% of digital transformations fall short of their objectives.[98] Digital transformation goes far beyond the simple adoption of digital technologies as it also means reinventing organisations and embracing a philosophy of change to adopt new (data-driven) business models. Therefore, the increasing digitalisation wave requires not only new technical skills (e.g., data analytics) but also managerial and leadership ones. In other words, in order to thrive in the digital scenario, organisations need a new class of executives aware of the challenges and the dynamics of digital transformation. This is particularly relevant if we think that "new management roles will increasingly be distributed at the jobsite […] thanks to automation and remote control, the operator who was heretofore sitting in the truck and moving around the construction site will now have to sit in an office, coordinating three machines at once"[99] thus making managerial and the planning skills to coordinate a complex site more important than ever.

[97] *Ibid*. page 36.
[98] *Flipping the Odds of Digital Transformation Success,* Forth, Reichert, de Laubier, Chakraborty, 29 October 2019, available here: https://www.bcg.com/publications/2020/increasing-odds-of-success-in-digital-transformation.
[99] *Digitalising the construction sector – Unleashing the potential of data with a value chain approach*, CECE, January 2019, page 36.

4. The European way to the Digital Age

"We must make this Europe's Digital Decade.

There are three areas on which I believe we need to focus.

First, data. […] The second area we need to focus on is technology – and in particular artificial intelligence. […] The third point is the infrastructure. […]

We want to lead the way, the European way, to the Digital Age: based on our values, our strength, our global ambitions." [100]

i. Setting the scene: an introduction

The words in the above introduction are those of the President of the European Commission during her last State of the Union (SOTEU) held on 16 September 2020. It is indeed widely recognized that digitalisation can bring a new wave of prosperity to the EU. According to Deloitte, "if investment was to drive all EU Member States to a DESI[101] score of 90 by 2027 (the end of the Multiannual Financial Framework), GDP per capita across the EU would be 7.2% higher at the end of the period."[102]
As stated in the recent COM(2021) 118 *2030 Digital Compass: the European way for the Digital Decade*, "in just a year, the COVID-19 pandemic has radically changed the role and perception of digitalisation in our societies and economies, and accelerated its pace. […] The pandemic has also exposed the vulnerabilities of our

[100] SOTEU 2020, President von der Leyen's speech, 16 September 2020.
[101] The Digital Economy and Society Index (DESI) is a composite index that summarises relevant indicators on Europe's digital performance and tracks the evolution of EU Member States in digital competitiveness. Link: https://ec.europa.eu/digital-single-market/en/digital-economy-and-society-index-desi
[102] *Digitalisation, an opportunity for Europe*, Deloitte, February 2021.

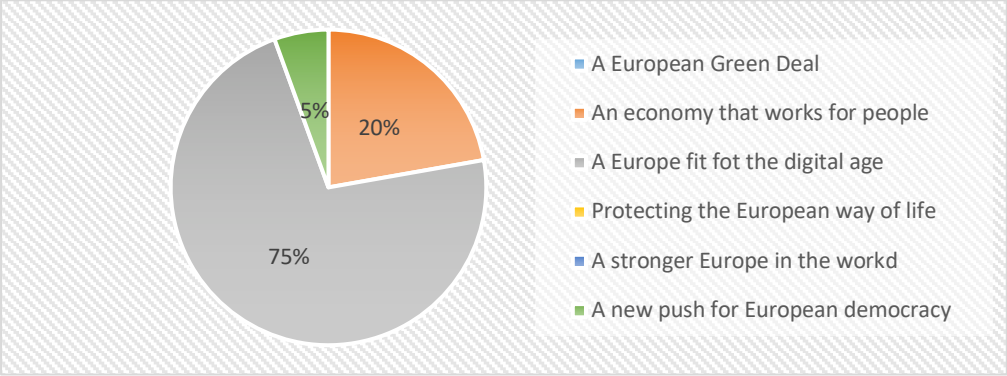
digital space, its dependencies on non-European technologies, and the impact of disinformation on [EU] democratic societies."[103] The SOTEU addressed to the EU Parliament mentions all the ingredients of the EU strategy on digitalisation and stresses the importance of "a common plan for digital Europe with clearly defined goals for 2030, such as connectivity, skills and digital public services" to lead the European way to the Digital Age "based on [EU] values" [104]. The same COM states that the "European way to a digitalised economy and society is about solidarity, prosperity, and sustainability, anchored in empowerment of its citizens and businesses, ensuring the security and resilience of its digital ecosystem and supply chains." From SOTEU, we can infer that the concept of the European way is linked to a plethora of different aspects such as technological sovereignty in key technology areas, a better legislative framework with fair and transparent liability and safety rules for digital platforms as well as for digital products and services, a push for the adoption of common standards at EU level, the enhancement of digital literacy, a higher protection of consumers' and citizens' rights, etc. All elements that are reflected in the official documents of the EU strategy. In fact, in order for digitalisation to thrive "Europe has to build on its strengths such as an open and competitive single market, strong rules embedding European values, being an assertive player in fair and rule-based international trade, its solid industrial base, highly-skilled citizens and a robust civil society."[105]

Let me now continue the discussion with a simple exercise. As a starting point, I ran a simple research experiment using the word "digital" in the political guidelines contained in the document *A Europe that strives for more* presented by the EU Commission in July 2019. Before going to the results, it is worth mentioning that the Political Guidelines for the period 2019-24 focus on the six following priorities:

[103] COM(2021) 118 final, *2030 Digital Compass: the European way for the Digital Decade*, 9 March 2021, page 1.
[104] SOTEU 2020, President von der Leyen's speech, 16 September 2020.
[105] COM(2021) 118 final, *2030 Digital Compass: the European way for the Digital Decade*, 9 March 2021, page 1.

- A European Green Deal.
- An economy that works for people.
- A Europe fit for the digital age.
- Protecting our European way of life.
- A stronger Europe in the world.
- A new push for European democracy.[106]

This simple exercise reveals that the word appears 20 times and it is distributed as follows.



As expected, the section *A Europe fit for the digital age* takes up the lion's share. However, it is worth spending a little time explaining why the concept of digitalisation is also mentioned in another two sections of the document. The reason is because the digital revolution has important repercussions on other aspects related to EU policy-making. For example, in the section *An economy that works for people,* relevant themes such as the conditions of platform workers, fair taxation (especially of big tech companies) are mentioned, while in the section *A new push for the European democracy* the attention is focused on the role of digital platforms in modern democracy, and specifically on the spread of disinformation and hate

[106] *A Europe that strives for more*, My agenda for Europe by candidate for President of the European Commission Ursula von der Leyen, page 4.

messages. While digging deeper into the section *A Europe fit for the digital age*, we come across the main the areas addressed by EU policy, notably technology, regulation, public policies, skills, and competences. We should not be neglect the fact that the Commission wants to "practice what it preaches" and lead by example, by embarking on an ambitious plan of digital transformation internally. Moreover, it wants to push for enhanced digital diplomacy tools.[107]

In short, this introduction is intended to give the reader a quick overview of the relevant traits of the EU digital strategy and setting the framework for further analysis. In particular, it was my intention to acquaint the reader with the concept of the "European way" to the digital age, which will be further explored.

It is now time to start digging into the political documents on the EU digital strategy, and in particular on the package released in February 2021(also known as the February package) that consists of three COMs[108]: *Shaping's Europe's digital future*, the *European Strategy on Data* and the *White Paper on Artificial Intelligence.*

From the methodological point of view, the research presented in the current chapter combines desk research with in-depth interviews to EU officials from several Directorate-Generals (in particular DG CNECT, DG GROW and DG EMPL) that are directly involved in policymaking and project management in the digital field, with a focus on the construction sector. The scope of this section is to provide meaningful insights on the nature and potential impact of the EU strategy by identifying the red thread that makes the EU Strategy singular in its scope and objectives. The results presented here are intended to provide a reliable source of intelligence to help understand the way the EU institutions are driving the process of digital transformation, which in turn will have important implication for the business sector

[107] In this context we consider digital diplomacy as he use of digital tools to achieve foreign policy goals. For further information, please check the working paper "*The Digitalization of Diplomacy*", Ilan Manor, 2018, available here: https://www.qeh.ox.ac.uk/sites/www.odid.ox.ac.uk/files/DigDiploROxWP2.pdf

[108] COM stays for COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. The COMs are the documents where the strategic policies of the EU Commission are explained.

and its evolution in the years to come. In short, the results presented here should become valuable instruments for the reader to make sense of the complexity of the digitalisation phenomenon as presented and approached in the strategy of the EU Commission, which is notably centred on the concept of "The European way to the digital age". For the sake of clarity, the content presented here is the result of my interpretation. Therefore, I did not engage the European Commission in any way in arriving at the results presented in this chapter that fall under my sole responsibility.

ii. Unveiling the EU digital strategy

The February package represents the backbone of the EU digital strategy as well as being one of the top priorities of the von der Leyen's Commission together with the Green Deal – in fact, the official documents always refer to the twin digital and green transformation. Besides focusing on the three COMs mentioned in the previous paragraph, this section will also take into account some aspects of the COM *A New Industrial Strategy for Europe*[109] released in March that is inherently linked to the previous ones. Based on the intentions set in the introductory section, the content of the abovementioned documents will be carefully scrutinized in order to shed light on the meaning and implications of the "European way to the digital age" approach, as pushed forward by the EU Commission.

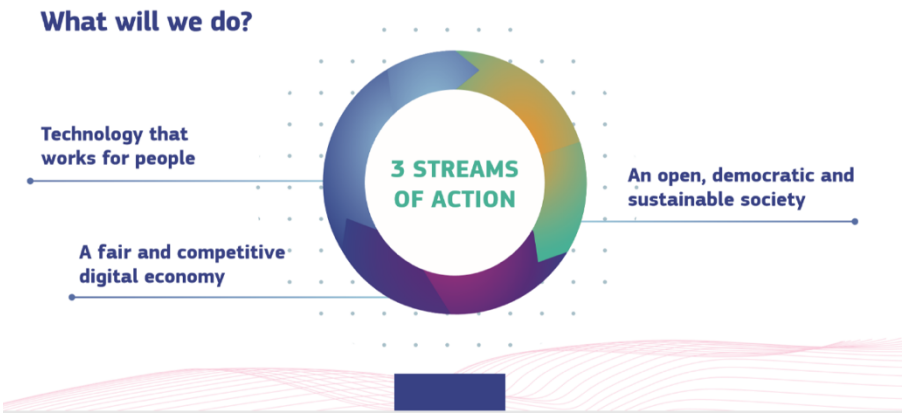
Relevant clues as to the EU strategy can be identified in the COM *Shaping's Europe's digital future*:

> *The Commission wants a European society powered by digital solutions that are strongly rooted in our common values, and that enrich the lives of all of us: people must have the opportunity to develop personally, to choose freely and safely, to engage in society, regardless of their age, gender or professional background. Businesses need a framework that allows them to start up, scale up, pool and use data, to innovate and compete or cooperate on fair*

[109] COM(2020) 102 final, 10 March 2020.

terms. And Europe needs to have a choice and pursue the digital transformation in its own way.[110]

The COM also identifies three objectives that the Commission will pursue "on the road towards digital transformation that works for the benefit of people through respecting our values" as exemplified in the infographic below.



Source: EU Commission

In short, the Commission wants to put people at the centre of the entire process of digital transformation. Therefore, digital technologies must serve the interests of the EU citizens and to contribute to the economic growth of the EU without neglecting the importance of the EU values of democracy, openness and sustainability.
It is increasingly recognized that "the crisis […] exposed the vulnerabilities of our digital space, its increased dependency on critical, often non-EU based technologies, highlighted the reliance on a few big tech companies, saw a rise in an influx of counterfeit products and cyber theft, and magnified the impact of disinformation on our democratic societies." Moreover, "a new digital divide has also emerged, not only between well-connected urban areas and rural and remote territories, but also between

[110] COM(2020) 67 final, *Shaping Europe's digital future*, 2020, page 3.

those who can fully benefit from an enriched, accessible and secure digital space with a full range of services, and those who cannot."[111] In fact, European players' weight in the global market in key technology areas is quite low as testified by the fact that 90% of EU's data are managed by US companies, less than 4% of top online platforms are European and European made microchips represent less than 10% of the European market.[112]

In order to address this gap, the Commission identified the most important ingredients for a successful digital strategy such as investments in cross-cutting edge technologies and infrastructure regarding connectivity, investments microelectronics and in the ability to process vast data amounts, the adoption of commonly recognized standards and higher interoperability in key digital infrastructure at EU level and beyond, the update in the legal framework in fields like AI, platform workers, competition law, the setup of a joint Cyber unit to face the threat of cyber-attacks, strengthened investments in digital skills to empower the EU citizens to the challenges of digital transformation, and so on. In short, three macro-areas seem to be at the centre of the EU strategy: technology and infrastructure, legislation, new skills and competences for the digital age.

The strategic documents issued by the European Commission also sketch a potential way to the digital age by focusing on what are supposed to be its main drivers: data and AI. It is indeed recognized that "digital communication, social media interaction, e-commerce, and digital enterprises […] are generating an ever-increasing amount of data, which, if pooled and used, can lead to a completely new means and levels of value creation. It is a transformation as fundamental as that caused by the industrial revolution." [113] This is because digital technologies are increasingly penetrating every aspect of our everyday life to such a point that, according to opinion of some prominent experts, the changes triggered by new digital technologies will "alter the way we live, work, and relate to one another."[114]

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[111] COM(2021) 118 final, page 2.
[112] *Ibid*, footnote 8.
[113] COM(2020) 67 final, *Shaping Europe's digital future*, 2020, page 3.
[114] Klaus Schwab, *The Fourth Industrial Revolution: what it means, how to respond***,** 14 January 2016.

In conclusion, two pillars sit at the centre of the digital revolution: data and AI. Therefore, it should come as no surprise that they are the object of the two COMs a *European Strategy on Data*[115] and the *White Paper on Artificial Intelligence.*[116] How the EU handles the challenges stemming from data and their exploitation (i.e. though the use of AI) will be pivotal for the EU economy to thrive and maintain its competitiveness in the years to come vis-a-vis alternative existing models (i.e. in China and US), as I will explain in more detail below. Therefore, EU policies on data and Artificial Intelligence will be treated separately in the next two sections.

a) The single market of data

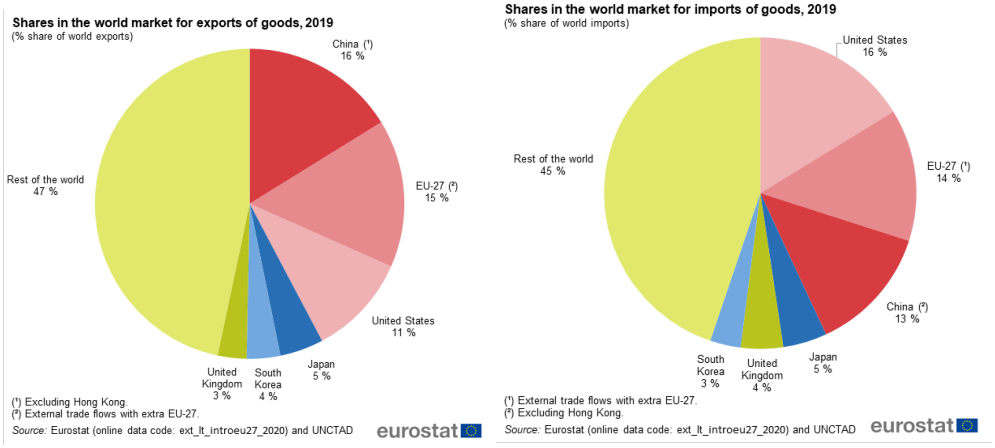
There is now widespread consensus on the fact that data has the power to transform all sectors of the economy as well as to improve our life and work conditions. In that regard, both personal and non-personal data can be a source of innovation for new products and services. However, according to some studies a significant percentage of data sits unused in organizations.[117] If data stays dormant and locked into big repositories where no access is granted, then no added value can be generated for the benefit of businesses and society as a whole. Our world is rapidly changing, and future competitiveness will not depend on the mere advantage of sitting on a pile of data but rather on the capacity of a society to capitalize on its potential by stimulating higher bottom-up participation in value generation from data and enhancing the level of wealth of the entire ecosystem affected.

In a recent article, Daron Acemoglu depicts a scenario that goes to the heart of the matter: "The problem today is not just that Big Tech has grown to a gargantuan size […] It is that all other market players have little choice but to make their own products and services interoperable – and thus dependent on and subordinate to – the major platforms." He adds that "a few of the largest U.S. and Chinese tech companies account for as much as two-thirds of global spending on AI development" to show

[115] COM (2020)66 final, *A European strategy for data.*
[116] COM(2020)65, *White paper on artificial intelligence*.
[117] Several studies tend to confirm that the percentage of data unused in organisations percentage varies between 60% (Forrester) to 97% (Gartner).

that the lack of diversity in R&D is very costly "when one considers the many alternative technologies and platforms that could otherwise be open to us."[118]

The EU strategy instead is driven by a strong commitment to tap into this "diversity" and propose an alternative model based in its values,[119] thus pushing every player in the continent and beyond to abide by the rules of the game. In order to understand the logic, the magnitude and the potential success of this approach, we shouldn't forget that the EU can leverage on the power and size of its internal market, which is also "the centrepiece of the EU's economic success"[120]. A few numbers might give us a better perspective. According to Eurostat, in 2019 the EU-27's exports of goods were equivalent to 15.4 % of the world total. Only China (16.2%) had a higher share while the United States (10.6%) lagged some distance behind. Concerning imports, The United States had a larger share of world imports (16.2 %) than either the EU-27 (13.7 %) or China (13.1 %) in 2019.[121]



Source: Eurostat

[118] Daron Acemoglu, *Antitrust Alone Won't Fix the Innovation Problem,* Project Syndicate, 30 October 2020, https://www.project-syndicate.org/commentary/google-antitrust-big-tech-hurdle-to-innovation-by-daron-acemoglu-2020-10?barrier=accesspaylog

[119] Values here are intended as those enshrined EU Treaties and in Charter of Fundamental Human Rights.

[120] COM(2014)14 final, *For a European Industrial Renaissance*, page 3.

[121] Eurostat, International trade in goods, https://ec.europa.eu/eurostat/statistics-explained/index.php/International_trade_in_goods

With its 512 million citizens and a GDP per capita of €25,000, the EU Single Market is still the world's largest trading block and the world's largest trader of manufactured goods and services.[122] Moreover, this specific approach to the digital strategy is inexorably rooted in the history of the EU and of the EU integration process and (most probably) upon its strengths will depend the success of the European way to the digital age. Let's now turn to the details of the data strategy.

Several studies show that the volume of data produced in the world is rapidly growing and that it will increase from 33 zettabytes in 2018 to 175 zettabytes in 2025[123] because of the massive spread and adoption of digital technologies in every aspect of our lives. While in the past data was confined to research community laboratories, this is no longer the case. On the contrary, it is increasingly scattered throughout society mostly because of the massive increase of IoT technologies and smart devices (i.e. mobile phones). According to some estimates, the number of sensors connected to the internet is expected to dramatically rise to 150 billion in the next few years while doubling time[124] is supposed to shrink to 12 hours by 2025 compared to one year in 2017. Data is considered the "lifeblood of economic development […] and the basis for many new products and services"[125] that will bring substantial benefits to the economy and the society as a whole. In addition, it's worth mentioning that data "can be replicated at close to zero cost and its use by one person does not prevent the simultaneous use by another person or organization." Data is often referred to the new oil of the digital age. However, it is worth pointing out one significant difference: data is a non-rival economic good, which means that it can be used by many individuals (or organizations) at the same time and for an infinite number of times[126]. Therefore, in order to generate economic and social gains

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[122] For further information, visit the following website: https://ec.europa.eu/trade/policy/eu-position-in-world-trade/

[123] COM (2020)66 final, *A European strategy for data*, page 2.

[124] Doubling time refers the time it takes for all the quantity of data produced in the history of humanity up to a certain point to double.

[125] COM (2020)66 final, *A European strategy for data*, page 2.

[126] Charles I. Jones and Christopher Tonetti, *Nonrivalry and the Economics of Data,* American Economic Review 2020, 110(9): 2819–2858 (https://christophertonetti.com/files/papers/JonesTonetti_DataNonrivalry.pdf)

"data should be [made] available to all, from public to private, from SMEs and start-ups to large companies."[127]

The EU effort is aimed at creating "a single European data space – a genuine single market for data, open to data from across the world –where personal as well as non-personal data, including sensitive business data, are secure and businesses also have easy access to an almost infinite amount of high-quality industrial data […]. This should foster an ecosystem (of companies, civil society and individuals) creating new products and services based on more accessible data."[128]

This approach shows important differences from the US counterpart "where the organization of the data space is left to the private sector, with considerable concentration effects", whereas Chinese "has a combination of government surveillance with a strong control of Big Tech companies over massive amounts of data without sufficient safeguards for individuals."[129] Conversely, the EU model rests on a strong legal framework based on values such as privacy, security, safety, and ethical standards that entails a better flow of data within the EU and across sectors and a higher exchange of high-quality data across sectors. In order for that to happen, the EU intends to ensure the full respect of European values and rules as well as the adoption of practical and clear data governance mechanisms.

Four major elements sit at the core of the EU strategy: the creation of a governance framework for data access and use, solid investments in technologies, infrastructure and governance mechanisms (the so-called "enablers") for the achievement of the single market of data, investments in skills and competences for the digital age and the rollout of common European data spaces[130] in crucial economic sectors and domains of public interest, also taking into account data governance and practical arrangements.

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[127] COM (2020)66 final, *A European strategy for data*, page 2.
[128] *Ibid*. 4-5.
[129] *Ibid*. 3.
[130] The specific data spaces described the image and currently under development are mentioned in the Appendix to the COM(2020)66 final.

As already mentioned above, in order to be exploitable, data must be available and of good quality. Therefore, specific measures are envisaged to favour and support data-sharing at different level, such as from government to business, from business to business and from business to government. For instance, the Commission envisages making public sector data available for free and in machine-readable format and through standardized APIs to open up new opportunities (Act on high value data sets, Q1 2021). In addition, it will work on a governance structure to facilitate cross-border and cross-sectorial data exchange in order to facilitate the use of data among different players thus incentivising innovative business opportunities. Issues such as standardization and interoperability will have to be tackled to favour harmonized transfer of data from one sector to another without creating entry barriers (Data Governance Act, Q4 2020). In that regard, the Commission intends to set up "governance structures and mechanisms that will create a coordinated approach to using data across sectors and Member States would help stakeholders in the data economy to capitalise on the scale of the internal market." [131] Concerning the legal basis of the Data Governance Act, Article 114 TFEU is identified as the relevant legal basis for this initiative and this would be in full respect of the provisions on anti-competitive practices and the ban on the abuse of dominant market power, as laid out in Articles 101 and 102 of the Treaty on the Functioning of the European Union (TFEU).[132] In particular, pursuant to this Article, the EU has to adopt measures for the approximation of the provisions laid down by law, regulation or administrative action in Member States which have as their object the establishment and functioning of the internal market in the EU."[133] This initiative, which is distinct from the Digital Markets Act (DMA) and the Digital Services Act (DSA) presented a few paragraphs below, aims at "improving voluntary data sharing within and across common European data spaces" by "supporting the emergence of data intermediaries that

[131] COM(2020) 767 final, *Proposal for a Regulation of the European Parliament and of the Council on European data governance (Data Governance Act)*, 2020, page 2.
[132] SWD(2020) 295 final, *Impact Assessment Report accompanying the Proposal for a Regulation of the European Parliament and of the Council on European data governance*, 2020, pages 17-18.
[133] COM(2020) 767 final, *Proposal for a Regulation of the European Parliament and of the Council on European data governance (Data Governance Act)*, 2020 page 2.

could organise data spaces as trusted third parties and provide relevant technologies. In addition, it would support the development of technical and legal standards relating to the means of the data exchange which, in turn, will enhance trust in data sharing. The current initiative covers different types of data intermediaries, handling both personal and non-personal data" and it "aims at facilitating data sharing including reinforcing trust in data sharing intermediaries that are expected to be used in the different data spaces."[134] In short, the Data Governance act sets a framework in order to "encourage greater reuse of data by data through increasing trust in data intermediaries and strengthening various data-sharing mechanisms across the EU".[135] In that regard, it focuses on the reuse of public sector data, it imposes obligations on providers of certain data-sharing services, it pushes for a higher "data altruism[136]" to favour data exchange and it announces the establishment of a European Data Innovation Board chaired by the EU Commission to secure the application of the act in Member States.

In general, potential limits to data sharing such as legal liability need to be tackled for a smooths flow of data to happen and actions to incentivize the exchange, preferably through voluntary mechanisms or where not possible – for instance in cases where clear market failures are identified – through fair and transparent compulsory ones.[137] For the single market to thrive, it is necessary to identify widely accepted and shared mechanisms of data governance that can increase trust among parties thereby opening the way to new opportunities for data sharing. Moreover, particular emphasis should then be placed in preserving "data security when data are being exchanged". In particular, "ensuring the continuity of access controls (i.e., how the security attributes of data are managed and respected) across data value chains will be a key, insisting

[134] SWD(2020) 295 final, *Impact Assessment Report accompanying the Proposal for a Regulation of the European Parliament and of the Council on European data governance*, page 6.
[135] https://iapp.org/news/a/proposal-for-an-eu-data-governance-act-a-first-analysis/
[136] As mentioned in COM(2020) 767 final, data altruism means data voluntarily made available by individuals or companies for the common good
[137] As mentioned in SWD(2020) 295 final, this legislative initiative will reinforce the development of European data spaces.

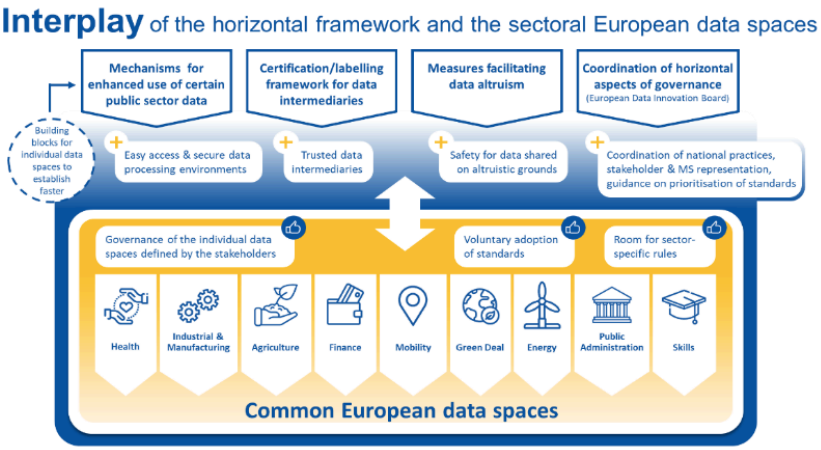
on the pre-requisite of fostering data sharing and ensuring trust among the different actors of European data ecosystems.[138]

One important aspect concerns the concentration of data in the hands of a limited number of large players – notably Big Tech companies – that will create significant imbalances in bargaining power among market players if not properly tackled. It is increasingly recognized that large players can benefit from insights stemming from the richness and variety of data they sit on and, consequently, they can dictate the conditions for access and use of data, which represents per se an advantage *vis-à-vis* potential competitors in all the sectors where they operate. In this regard, the Commission is considering ways to address these market imbalances regarding platforms and data though *ex-ante* regulation, if appropriate, in the framework of the work conducted by the Observatory of the Online Platform Economy. This is, the objective of the reform package issued by the EU Commission on December 16th, 2020 that is composed of the Digital Services Act and the Digital Markets Act. Metaphorically speaking, the Commission compared the Digital Service Act to the invention of the traffic light in Cleveland aimed at introducing rules that put order in the chaos of online traffic.[139] The Digital Services Act rests on three main actions: safety for users, transparency of platforms and better enforcement. That means that EU binding regulation will oblige online intermediaries (online platforms), and especially very large players that "are systemic in nature[140]" and that "have emerged as quasi-public spaces for information sharing and online trade" to swiftly act to remove illegal content or to block the selling of illegal goods or services online.[141] The proposal contained in the Digital Markets Acts instead complements the vigilance in competition law enforcement and wants to address the "negative

[138] COM (2020)66 final, *A European strategy for data*, page 11.
[139] Statement by Executive Vice-President Vestager on the Commission proposal on new rules for digital platforms, 15 December 2020 (https://ec.europa.eu/commission/presscorner/detail/en/STATEMENT_20_2450).
[140] The European Commission considers that Platforms that reach more than 10% of the EU's population (45 million users) are considered systemic in nature, and are subject not only to specific obligations to control their own risks, but also to a new oversight structure.
[141] *Europe fit for the Digital Age: Commission proposes new rules for digital platforms*, 15 December 2020, https://ec.europa.eu/commission/presscorner/detail/en/ip_20_2347.

consequences arising from certain behaviours by platforms acting as digital gatekeepers to the single market" by imposing a specific set of obligations. In particular, the Commission proposes among other things to ban large platforms from using the data businesses they host when competing against them, to increase interoperability of their services so as not to exclude competing providers and to adjust the search algorithm in order to breach the self-preferencing practice, which means avoiding making their services more favourably than those of their competitors. In the case of non-compliance, fines up to 10% of the worldwide turnover and even actions to dismantle powerful corporate structures in case of recurrent infringements are envisaged.[142]

The Commission is then determined to increase investments in enablers. In that regard, particular attentions shall be placed on the launch of the High Impact Project on data spaces that will cover the period 2021-27 (see image below) and that will be financially supported by the two programmes Digital Europe and Connecting Europe Facility. This pilot project is aimed at funding "data-sharing tools, architectures and governance mechanisms for thriving data-sharing and Artificial Intelligence ecosystems […] based on the European federation of energy-efficient and trustworthy edge and cloud infrastructures."[143]



[142] Statement by Executive Vice-President Vestager on the Commission proposal on new rules for digital platforms, 15 December 2020 (https://ec.europa.eu/commission/presscorner/detail/en/STATEMENT_20_2450).
[143] COM (2020)66 final, *A European strategy for data*, page 16.

Source: EU Commission

This pilot project is aimed at funding "data-sharing tools, architectures and governance mechanisms for thriving data-sharing and Artificial Intelligence ecosystems […] based on the European federation of energy-efficient and trustworthy edge and cloud infrastructures."[144]

Generally speaking, the Commission intends to boosts investment in new digital technologies and infrastructures under several programmes[145], mainly because "digital transformation of the EU economy depends on the availability and uptake of secure, energy-efficient, affordable and high-quality data processing capacities, such as those offered by cloud infrastructures and services, both in data centres and at the edge" and so "the EU needs to reduce its technological dependencies in these strategic infrastructures, at the centre of the data economy."[146]

To achieve adequate results, the EU commits to provide about €2 billion in co-funding for a total investment of €4-6 billion. The project serves manifold purposes: "EU-wide common, interoperable data spaces aim at overcoming legal and technical barriers to data sharing across organisations, by combining the necessary tools and infrastructures and addressing issues of trust, for example by way of common rules developed for the space. The spaces will include: (i) the deployment of data-sharing tools and platforms; (ii) the creation of data governance frameworks; (iii) improving the availability, quality and interoperability of data."[147]

One part of the project will be focused on the cloud federation in order to favour a higher level of interconnection between edge computing capacities and the cloud with the aim to foster the growth and the exploitation of the Common European data spaces for public, industrial and scientific applications.[148] In that regard, the EU intends to sign Memoranda of Understanding with Member States in order to create

[144] COM (2020)66 final, *A European strategy for data*, page 16.
[145] Discussion about different funding programmes in support of digital transformation is in section 6 of the current chapter.
[146] COM (2020)66 final, *A European strategy for data*, page 9.
[147] *Ibid*, page 17.
[148] *Ibid*, page 17.

synergies with similar cloud federation initiatives launched at national level (i.e. Gaia-X[149]) and avoid unnecessary fragmentation and data-sharing initiatives.
In the same way, in collaboration with Members States, the EU will also ensure that cloud providers operating in the EU abide by the existing rules (e.g., GDPR) and in addition it will create an EU (self) regulatory cloud rulebook[150] for cloud providers and users with a coherent framework around the different applicable rules. In addition, the Commission envisages the launch of a European cloud services marketplace whose participation will be linked to the respecting a number of requirements in areas like data protection, security, data portability, energy efficiency and market practice (e.g. transparent and fair contract conditions). To boost change, the public sector will play an important role on a twofold level: by setting common European standards and requirements for the public procurement of data processing upfront and by supporting the marketplace as with public sector procurement of solutions that abide by the rules. While representing a way to potentially increase trust on the users' side, this will also oblige large players to adapt to the new regulatory framework when dealing with consumers in the EU market.
One last fundamental element is relevant which concerns the role of individuals in the new digitalized society. According to the EU Commission, "in a society where individuals will generate ever-increasing amounts of data, the way in which the data is collected and used must place the interests of the individual first, in accordance with European values, fundamental rights and rules." Beside ethical considerations about the rights of individuals, there is an economic element that cannot be neglected: the importance of trust. For citizens to participate in the digitalization process actively and consciously, they must be empowered to face the challenges of the digital

[149] According to Wikipedia, "GAIA-X is a project for the development of an efficient and competitive, secure and trustworthy data infrastructure for Europe, which is supported by representatives of business, science and administration from Germany and France, together with other European partners" and it aims aim developing common requirements for a European federated, open data infrastructure based on European values. For further information, visit the official website: https://www.data-infrastructure.eu/GAIAX/Navigation/EN/Home/home.html
[150] COM (2020)66 final also states that "in the first instance, the cloud rulebook will offer a compendium of existing cloud codes of conduct and certification on security, energy efficiency, quality of service, data protection and data portability", page 18.

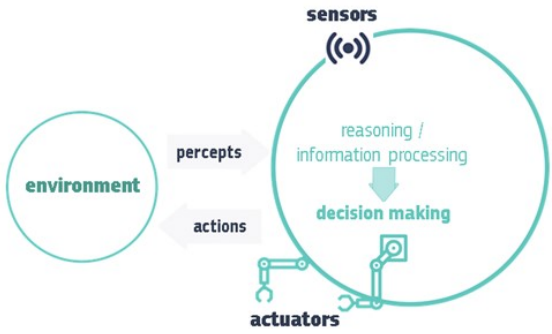
revolution. For this to happen, two elements are particularly relevant: digital skills and digital rights. New skills and competences are increasingly required in the job market; therefore, attention should be placed to the improvement of the digital education ecosystem as well as to enhance digital skills and competences (Digital Education Plan). Also, SMEs will benefit from initiatives aimed at upgrading skills necessary for digital transformation to become a reality. It is worth mentioning that "the European Pillar of Social Rights Action Plan projects the target for adults with at least basic digital skills to 80% in 2030". However, "advanced digital skills require more than mastering coding or having a foundation in computer science" so "digital training and education should support a workforce in which people can acquire specialised digital skills to get quality jobs and rewarding careers."[151]
In addition, individuals must be given the right to decide what to do with their own data which in turn promises "significant benefits […] including to their health and wellness, better personal finances, reduced environmental footprint, hassle-free access to public and private services and greater oversight and transparency over their personal data."[152]

b) Making sense of complexity: AI in the EU strategy

It is now time to proceed on our journey into the core of the EU strategy. Which in this case also coincides with the "journey of data", namely the process that goes from data to information, from information to knowledge and eventually to culture. For the sake of clarity, in this context culture can be defined as "the ensemble of intellectual cognitions acquired by an individual through the study and the experience, and in particular through a process of re-elaboration with personal and deep thinking so as to convert notions from simple erudition to a constituent element of his moral

[151] COM(2021) 118, final. The same document shows some numbers that give us a better idea of the situation. In fact, "as of 2019, there were 7.8 million ICT specialists with a prior annual growth rate of 4.2%. If this trend continues, the EU will be far below the projected need of 20 million experts e.g. for key areas, such as cybersecurity or data analysis. More than 70% of businesses report a lack of staff with adequate digital skills as an obstacle to investment."
[152] *Ibid*.

personality, his spirituality and his aesthetic taste, in summary, in the awareness of the self and of his own world."[153] I'll come back to this definition a little later.
First, let us start by defining AI. In this context, I adopted the definition in the report of the High Level Expert Group on Artificial Intelligence that defines AI as "software (and possibly also hardware) systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information, derived from this data and deciding the best action(s) to take to achieve the given goal."[154]

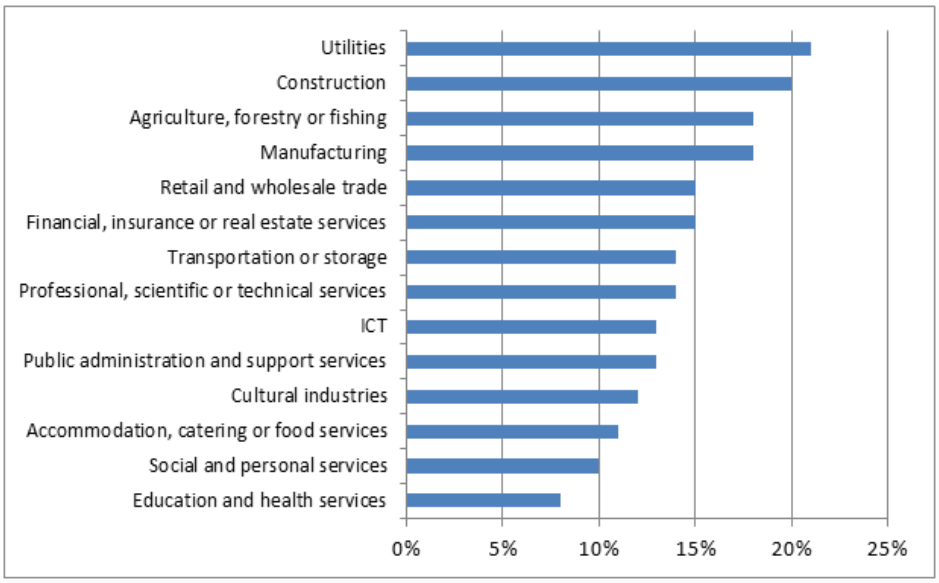


Source: AI HLEG

The image illustrates how AI works: thanks to the use of sensors, the system can perceive "the environment in which the system is immersed […], thus collecting and interpreting data, reasoning on what is perceived or processing the information derived from this data, deciding what the best action is, and then acting accordingly, through some actuators, in so doing possibly modifying the environment."[155] The reader has probably noticed the extent to which this process (at least partially) mirrors the definition of culture mentioned in the paragraph above.
The AI revolution represents a significant moment for the EU and the world, to the extent that it can be compared to the invention of the Gutenberg printing press in the

[153] Treccani, https://www.treccani.it/vocabolario/cultura/
[154] *A definition of the AI*, HLGE, 8 April 2019, page 6, https://ec.europa.eu/digital-single-market/en/news/definition-artificial-intelligence-main-capabilities-and-scientific-disciplines
[155] *Ibid*, page 1.

XV century. One of the aims of AI is to decode human intelligence and incredible results have been achieved so far, giving raise consideration and questions regarding the future of humanity among a certain number of scholars. Thanks to their ability to learn from data (e.g., machine learning, deep learning) AI systems are now capable of performing a wide array of tasks such as recognize handwriting, describing pictures and videos, playing chess like real champions and even writing articles and paintings with remarkable results. This means that "blue collar workers" are not the only ones being impacted by the effects of digitalisation but there are also an increasingly important number of "white collar workers" who will have to face the consequences of such disruptive phenomenon. The graph below shows the share of EU workers at very high risk from automation by Industry, EU 28.



Source: Pouliakas (2018)

According to Future Impacts, automation might cause a loss of 2 billion jobs and the creation of 375 million by 2025/30. McKinsey estimates that 50% of current jobs can be theoretically automated. The 2018 ESDE Annual Review[156] states that between 37% to 69% of jobs in the EU could be partially automated in the future. AI and

[156] Employement and Social Developments in Europe, Annual Review 2018.

automation will impact several sectors, such as transportation, manufacturing, customer services, finance, health care and agriculture are particularly susceptible to automation. In particular, occupations where work organization is highly routinized and limited in social interaction, as well as jobs with relatively low level of educational requirements, are more likely to be automated.[157] However, AI and automation also bring significant opportunities. For instance, some studies[158] show that by 2035, AI has the potential to double the annual economic growth rates in developed economies. New jobs closely linked to the adoption of ICT technologies will emerge (maintenance, use and upgrade of new technologies) as well as jobs where human interaction and wisdom is required will continue to grow.

In any case, it comes as no surprise that the EU Commission recognizes that "AI is one of the most important applications of the data economy." The relationship between data and AI is clear if we consider that data access and data management are elements of paramount importance for the development of AI as well as other applications. But data per se is not enough, in order to reach digital sovereignty, the EU must secure key computing technologies and infrastructures. Despite being currently in a weak position vis-à-vis its international competitors (i.e., China and the US), a few recent developments might revolutionize the landscape in the years to come. In particular, "while today most data is related to consumers and is stored and processed on central cloud-based infrastructure […] a large share of tomorrow's far more abundant data will come from industry, business and the public sector, and will be stored on a variety of systems, notably on computing device working at the edge of the network" [159] thus potentially putting at stake the semi-monopolistic position of Big Tech online platforms. More specifically, "today 80% of the processing and analysis of data takes place in data centres and centralized computing facilities and 20% in smart connected objects, such as cars, home appliances or manufacturing robots, and in computing facilities close to the user ('edge computing')" while

[157] McKinsey, *Jobs lost, jobs gained: What the future of jobs will mean for jobs, skills and wages*, November 2017.
[158] Accenture, *Why Artificial Intelligence is the Future of Growth*, Purdy and Daugherty, 2016.
[159] COM(2020)65, *White paper on artificial intelligence*, 2020, page 2.

according to Gartner "these proportions are likely to be inverted in the next five years."[160].

This change might cause a shift in favour of the EU, whose competitive advantage lies more in digitised industry (i.e., robotics, where Europe produces more than a quarter of all industrial and professional service robots[161]) and B2B software applications for companies and organisations rather than in consumer platforms. Moreover, through initiatives such as the European Processor Initiative, the Key Digital Technology Joint Undertaking (foreseen for 2021) and other similar actions, the EU wants to boost its role in low power electronics and computing systems, as well as in quantum computing and algorithmic foundations of AI.

AI is also an important tool of foreign policy and it could be instrumental for the EU to "exercise global leadership in building alliances around shared values and promoting the ethical use of AI"[162] thus creating a level playing field worldwide and promoting the interest of EU players at international level.

The White Paper on artificial intelligence is centred on two major building blocks: the ecosystem of excellence and the ecosystem of trust. Under the "ecosystem of excellence" are grouped all the relevant initiatives aimed at mobilizing resources to fund R&I and support uptake of AI by public administration and industry, in particular SMEs.

[160] COM (2020)66 final, *A European strategy for data*, page 2.
[161] COM(2020)65, *White paper on artificial intelligence*, page 3.
[162] COM(2020)65, *White paper on artificial intelligence*, page 8.

As the name itself suggest, this block of initiatives is aimed at building excellence on AI in the EU at several levels, from research to implementation. In order to do so, the EU must firstly tackle a major investment problem: according to McKinsey, with its €3.2 billion invested in AI the EU still lags behind compared to the US and Asia, where the amount invested is €12.1 billion and €6.5 billion respectively (2016 data).[163] Therefore, it should come as no surprise that much of the effort under the first pillar is meant to attract and pool investments in areas "where the action required goes beyond what any single Member State can achieve"[164] to reach a yearly investment of €20 billion per year under a variety of different programmes such as the new Digital Europe Programme, Horizon Europe and the European Structural and Investment Funds.[165]

To reduce fragmentation, under the Digital Europe Programme and Horizon Europe the EU intends to establish a lighthouse centre of research innovation and expertise that will coordinate a network of world excellence and testing centres of reference, on AI in specific sectors where the EU has "the potential to become a global champion such as industry, health, transport, finance, agri-food value chains, energy/environment, forestry, earth observation and space". Such an initiative is aimed at reducing the level of fragmentation, pooling resources from the public and the private sector and to attract talent from all over the world. In that regard, as already mentioned in the previous sections, the EU will vigorously invest in world leading programmes on AI in collaboration with universities, higher education institutes and social partners.

In addition, the EU must ensure that industry, and in particular SMEs, can benefit from the advantages of AI technologies. In that regard, the Commission will collaborate with national authorities for the establishment of one Digital Innovation Hub (DIH) per MS to help SMEs understand and adopt AI technologies. Moreover, it will make use of the InvestEU instrument to provide equity financing for innovative

[163] McKinsey, *10 imperatives for Europe in the age of AI and automation* (2017).
[164] COM(2020)65, *White paper on artificial intelligence*, page 5.
[165] For a more detailed description of programmes and amounts, please see section … of the current chapter.

developments in AI.[166] In order to secure an adequate level of co-funding from the private sector, the Commission envisages the establishment of a new PPP in AI, data and robotics, that will contribute to set R&I agenda and work with DIHs and the excellence and testing centres, guaranteeing higher level of coordination among the different initiatives.

The second pillar "ecosystem of trust" concerns the regulatory framework aimed at building an ecosystem of trust by considering the ethical recommendations of the High-Level Expert Group on AI with the objective of favouring AI uptake from companies, in particular SMEs, and public organizations.

While defining the scope of future regulation, the European Commission recognizes once more the importance of the relationship between data and AI. It is then worth mentioning one additional element: the human factor. The White paper starts from the assumption that "while AI-based products can act autonomously by perceiving their environment and without following a pre-determined set of instructions […] Humans determine and programme the goals, which an AI system should optimize." In short, future AI will be what we want to make of it. This approach is radically different compared to its main competitors worldwide and it is directly inspired by the EU core values. For that reason, the European Commission intends to adopt a risk-based approach in its regulation efforts to ensure that the intervention is proportionate and not too prescriptive, so as not to cause harm due to the excessive burden on some players, in particular SMEs. This means that particular regulation should tackle high-risk applications that fulfil the cumulative criteria of being employed in sectors where significant risks can occur and be used in such a manner that significant risks are likely to arise.

[166] COM(2020)65, *White paper on artificial intelligence*, page 7.

In this context, respect for EU core values and rules means that AI enabled products or services have to be safe, non-discriminatory and that privacy and personal data must be adequately protected. In that regard, data sets used to train AI systems are supposed to be broad and sufficiently representative. Moreover, the programming of algorithms and in some cases the data used to train high-risk systems shall be recorded so that they can be further scrutinized by the competent authority to avoid potential misuses. When interacting with high-risk AI systems, citizens should be duly informed and they should be made aware about their capabilities, limitations, and most of all objectives. Beside the importance of having robust and reliable AI systems that impede cyber-attacks, breaches and manipulation, it is fundamental to guarantee an appropriate involvement of human beings in relation to high-risk AI applications at several level, from the design phase to the validation or ex-post checks on the outputs. A final point concerns biometric data, the use of which is currently strictly limited to specific circumstances and is highly regulated, it can represent a potential threat to fundamental rights and that needs to be consequently addressed in a harmonized way at EU level. And finally, the achievement of a trustworthy, secure and value-based AI will require a certain level of responsibility and commitment from the economic actors. In order to ensure that legal requirements are complied with, conformity assessment will be put in place in order to verify that high-risk AI applications are in line with the law. In that regard, Digital Innovation Hubs will play

a role in assisting SMEs in enforcing legal requirements without having them bear the burden of additional investment that might hamper competitiveness. But most of all, the abovementioned requirements will be applicable to every actor providing AI-enabled products and services in the EU market regardless of their place of origin, in order to guarantee a level playing field. As a matter of fact, this approach stems from the success of the GDPR that "has emerged as a reference point and acted as a catalyst for many countries and states around the world considering how to modernise their privacy rules." Besides being enforced in EU, this model inspired countries such as Chile, South Korea, Brazil, Japan, Kenya, India, Tunisia, Indonesia, Taiwan and the state of California, to name but a few. In addition, "international instruments, such as the modernized "Convention 108" of the Council of Europe, or the "Data Free Flow with Trust" initiative launched by Japan are also based on principles that are shared by the GDPR."[167]

In the optic of an economy that "strives for more", even economic actors not covered by legal obligations might decide to launch a voluntary labelling process not only to merely show compliance with the EU standards but also to satisfy the increasing attention on sustainability and ethical values from the market. In conclusion, for the strategy to succeed, a high level of coordination among EU and national authorities is required to reduce fragmentation and make the best use of the resources by leveraging on the strengths of the internal market.

c) The EU way to the digital age: what chances of success?

Let's now conclude our journey into the EU strategy by drawing some conclusions on the scope and nature of its action. It is important to shed light on the approach of the EU way to the digital age to evaluate its chances of success in years to come, especially if we consider that in the post-pandemic world economic hegemony will depend on the ability to steer the process of digitalisation and digital transformation.

[167]For further information see,
https://ec.europa.eu/commission/presscorner/detail/en/qanda_20_1166

We are now aware that the world is facing a disruptive revolution triggered by data and AI that will substantially change our lives in years to come. As illustrated by some prominent scholars[168], the disruptive effect of the new data and AI technologies represent both a technological and cultural revolution that can generate significant changes in the equilibrium of power worldwide. In that regard, thanks to the "bits" an increasingly larger share of the population will have access to knowledge opening the way to new and unforeseen opportunities and (possibly) profound changes in our everyday lives. There are some similarities between this revolutionary process and the process that lead to Renaissance, the Enlightenment and then to the Industrial Revolution, which represented a pivotal moment for the world order in terms of economic growth as well as on wealth generation and distribution.

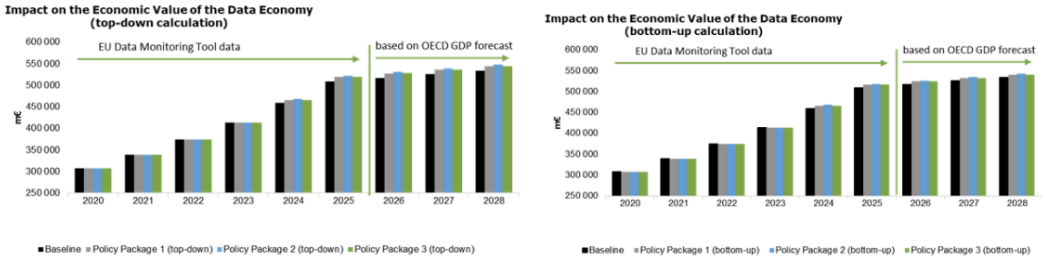
The quality of our future existence will depend on our ability to master this revolutionary phenomenon, for good (hopefully) and not for bad. The revolution has the potential to accelerate the spread of knowledge to every corner of the planet in a fast and cheap way. However, in the short term it will have disruptive impact on the labour market: millions of jobs will disappear while new jobs linked to the new digital paradigm will emerge. And these new jobs will be inexorably linked to the fundamentals of the "new world economy": data and its interpretation through AI systems. And in order for that to happen, data must first be accessible. Which does not mean free nor necessarily open to everyone (unless this is a precondition for the common good). On the contrary, the EU approach recognizes the fundamental role of market incentives as a driver of innovation and economic growth. However, the European Commission decided to play the role of regulator and to prevent potential failures in the digital single market by proposing a new framework for the digital age that limit potential abuses while putting the person at the centre of the process of digital transformation. Specifically, the EU wants to limit the (current and future)

[168] In this case I'm referring first and foremost to the conferences of Professor Mario Rasetti, president of the ISI Foundation of Turin, who extensively described the nature and the impact of Big Data revolution in a series of conferences available online. Other important contributions came from scholars such as Dirk Helbing, Professor of Computational Social Science at the ETH Zurich and Viktor Mayer-Schoenberger, Professor of Internet Governance and Regulation at Oxford.

excesses of giant tech conglomerates, whose monopolistic behaviour can distort competition, while guaranteeing every player (in particular small and medium ones) in the EU market a level playing field, especially concerning access to the most valuable commodity of the digital age: data.

Is the EU approach going to succeed? Some doubts may still arise regarding the economic impact of the EU regulatory approach on the competitiveness of the EU economy *vis-à-vis* other competitors. At the same time, some studies tend to confirm that the approach will generate a positive impact in socio-economic terms in the future, as is explained in the paragraphs below. Concerning data governance, the EU Commission started from the assumption that there are problems that hinder the potential development of the single market such as the lack of trust in data sharing, potential issues related to the reuse of public sector data, and technical obstacles (i.e., interoperability) to data reuse/exchange. In order to tackle these problems, action is required to reinforce data sharing, making more data available for use in the common European data spaces and overcoming technical obstacles. But what action? When selecting the best possible options in terms of policymaking, the Commission relied on the results of a detailed impact assessment[169] that shows four different scenarios from zero or no intervention to a soft regulatory intervention and then up to low and high intensity levels of intervention. The methodology used to run the analysis pays attention not only to the economic aspects but also on the social and environmental aspects, as well as the importance of SMEs to the EU economy. According to the study in the absence of policy and legal framework scenario "data economy and the economic value of data sharing are expected to grow to an estimated EUR 533.5 billion (3.87% of the GDP) by 2028" while the increase would be "between EUR 540.7 and EUR 544.4 billion (3.92% to 3.95% of the GDP) under the preferred option", which entails a mixture of low and high intensity regulatory measures.

[169] European Commission (2020). *Support Study to this Impact Assessment*, SMART 2019/0024, prepared by Deloitte.



Source: SMART 2019/0024

What is most important in the light of the above attention to EU values, is that "this policy option would make it possible to create an alternative European model for data sharing to the current business model for Big Tech platforms, through the emergence of neutral data intermediaries. This initiative can make the difference for the data economy by creating trust in data sharing as a precondition for the development of common European data spaces, where individuals and companies are in control of the data they generate and are comfortable with the way in which the data are used in innovative ways".[170] According to this interpretation, the whole will be more than the sum of its parts because the EU approach "would facilitate data sharing across the EU, unleashing the power of data-based innovation and supporting the creation of new services and products and more efficiency in the industry. It would also contribute to new tools for tackling societal challenges, such as climate change, and to better policymaking."[171] Moreover, individuals won't be stripped of their fundamental rights, especially for what concerns privacy, human dignity and trust. On the contrary investments will be channelled to empower individuals through ad-hoc educational and training paths as well as through awareness campaigns on the role and importance of data in the digital society. In short, this is the essence of the European way to the digital age.

Regarding the assumptions in the Digital Market Act, the reasons behind this intervention choice are articulated as they relate to those very elements that lie at the

[170] *Ibid*. page 54.
[171] *Ibid*.

core of the EU vision. It is worth noticing that the regulation draws inspiration from two public consultations, a stakeholder consultation on the interim reports by the Observatory for the Online Platform Economy, a series of conferences, workshops and other research conducted by the JRC and a structured dialogue with Member States. In most cases, there was a wide consensus on the need to tackle unfair practices by the so-called gatekeepers while "those disagreeing referred to the fact that the concept of a gatekeeper is too broad and should instead be assessed on a case-by-case basis and that the Commission can already intervene in the case of the conduct of a gatekeeper contravening Article 102 TFEU."[172] However, the Commission considered that this Article was not sufficient because "a gatekeeper may not necessarily be a dominant player, and its practices may not be captured by Article 102 TFEU if there is no demonstrable effect on competition within clearly defined relevant markets. Moreover, Article 102 TFEU does not always allow for the speedy intervention necessary to address these pressing practices in the most timely and effective manner."[173] When designing the type of intervention, a list of different scenarios was evaluated, and the choice fell on a "partially flexible framework of designation and updating of obligations, including regulatory dialogue for the implementation of some"[174] because of its positive impact. In particular, the increase in the contestability of core platform services and broader digital sector will favour the diversification of the market through the emergence of alternative platforms generating a positive impact on the overall economy. The list of potential benefits linked to the current initiative is remarkable: an increase of €92,8 billion in cross-

[172] According to the Article 102 of the TFEU, "Any abuse by one or more undertakings of a dominant position within the internal market or in a substantial part of it shall be prohibited as incompatible with the internal market in so far as it may affect trade between Member States." For further information, please refer to the Consolidated version of the Treaty on the Functioning of the European Union - PART THREE: UNION POLICIES AND INTERNAL ACTIONS - TITLE VII: COMMON RULES ON COMPETITION, TAXATION AND APPROXIMATION OF LAWS - Chapter 1: Rules on competition - Section 1: Rules applying to undertakings - Article 102 (ex Article 82 TEC).
[173] COM(2020) 842 final, *Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on contestable and fair markets in the digital sector (Digital Markets Act),* page 8.
[174] *Ibid*. page 9. I detail here the full list of options: Option 1 - Pre-defined list of gatekeepers and self-executing obligations; Option 2 -Partially flexible framework of designation and updating of obligations, including regulatory dialogue for the implementation of some; and Option 3 -Flexible option based exclusively on qualitative scoping thresholds.

border trade by 2025, an economic growth between €12 and €25 billion because of the higher investments in the EU27, a potential increase in employment levels between 136,387 and 294,236 units, higher investments in R&D in the ICT sector in the EU27 from between €12 and €23, a consumer surplus estimated at €13 billion to name but a few.[175]

In any case, the Commission totally committed to going down the road of the digital transformation of the continent and beyond. In order to strengthen its initiative and add a certain level of concreteness, it decided to set up a Digital Compass in the form of a digital policy programme to be adopted by co-decision of European Parliament and Council[176] in order "to translate the EU digital ambitions for 2030 into concrete targets and to ensure that these objectives will be met." This Compass "will be based on an enhanced monitoring system, to follow the EU's trajectory regarding the pace of a digital transformation, gaps in European strategic digital capacities as well as the implementation of digital principles"[177] and it is tentatively going to be proposed to the co-legislators by the third quarter of 2021.

However, doubts about the potential success of the EU strategy still exist because of several risks. Some scholars[178] state that in its efforts to create a level playing field, the EU regulatory might end up protecting the incumbents and minimise disruption rather than enhance the value-creating potential of platforms. It might even create a "market of the regulation" where a series of actors (i.e., consultants, large companies) might end up ensuring rent-seeking positions because of their stronger financial means, extended networks and political relationships. This in turn might become highly problematic in the digital context, where the disruptive element proves to be

[175] SEC(2020) 437/2 REGULATORY SCRUTINY BOARD OPINION Proposal for a Regulation of the European Parliament and of the Council on contestable and fair markets in the digital sector (Digital Markets Act).

[176] According to COM(2021) 118 final, this programme will be similar to the Radio Spectrum Policy Programme (RSPP) approved on 14 March 2012 by the European Parliament and Council. This Decision created a comprehensive roadmap, set general principles and called for concrete actions to meet the objectives of EU policies for radio spectrum use.

[177] COM(2021) 118 final.

[178] Andrej Savin, *Regulating internet platforms in the EU - The emergence of the 'Level playing Field'*, Computer Law & Security Review, Volume 34, Issue 6, 2018, Pages 1215-1231.

an important element of competitiveness. Given that regulation is fixed cost, this would be particularly onerous for SMEs. In addition, despite the EU effort to set up a network of Digital Innovation Hubs to assist SMEs in their compliance with any future regulatory framework, the result is far from granted. Asymmetries among EU countries in terms of institutional efficiency and mind-set might penalize some players, especially SMEs, and lead to further market distortions – this can be particularly harmful for the construction sector, already characterized by a significant level of fragmentation. To guarantee the equal treatment of all players, the process of digital transformation will have to be constantly monitored and potential deviations will have to be promptly addressed to avoid such a scenario. This leaves room for further research on this specific point, which has not addressed in the context of this work.

iii. Follow the money: funding in support of digitalisation.

At the time of writing, Europe is confronting the worst crisis of its entire history, namely the negative consequences that flow from the Covid-19 pandemic on the European economy and society. As a result, the European Union had to swiftly react and adapt its policy priorities to mitigate the negative consequences of the socio-economic crisis and set the stage for a rapid socio-economic recovery. As mentioned in the recent Staff Working Document of the EU Commission *Identifying Europe's Recovery Needs*, "what started as a localised outbreak of a previously unknown virus infection in late 2019 has rapidly spread across the globe, wreaking havoc on European and global health systems and economies in the process."[179] For many months, the COVID-19 pandemic hit EU Members States and the world with a devasting impact resulting a deep recession and profound socio-economic damages at global level. According to the Autumn 2020 Economic Forecast the euro area economy will contract by 7.8 % in 2020 and rebound by 4.2% in 2021 and 3% in

179 Staff Working Document *Identifying Europe's Recovery Needs*, 27 May 2020, p. 1.

2022, while the EU economy is expected to contract by 7.4% in 2020 and grow by 4.1% in 2021 and 3% in 2022 (see table 1 below).[180]

Table 1:

Overview - the autumn 2020 forecast

	Real GDP			Inflation			Unemployment rate			Current account			Budget balance		
	2020	2021	2022	2020	2021	2022	2020	2021	2022	2020	2021	2022	2020	2021	2022
Belgium	-8.4	4.1	3.5	0.4	1.4	1.6	5.9	7.0	6.2	0.7	0.6	0.4	-11.2	-7.1	-6.3
Germany	-5.6	3.5	2.6	0.4	1.4	1.3	4.0	4.0	3.8	6.2	6.6	6.6	-6.0	-4.0	-2.5
Estonia	-4.6	3.4	3.5	-0.5	1.4	2.1	7.5	7.8	6.7	2.8	2.0	1.2	-5.9	-5.9	-5.1
Ireland	-2.3	2.9	2.6	-0.5	0.3	1.6	5.3	8.9	8.7	5.7	0.2	-1.1	-6.8	-5.8	-2.5
Greece	-9.0	5.0	3.5	-1.3	0.9	1.3	18.0	17.5	16.7	-6.2	-6.4	-4.8	-6.9	-6.3	-3.4
Spain	-12.4	5.4	4.8	-0.2	0.9	1.0	16.7	17.9	17.3	1.8	2.5	2.8	-12.2	-9.6	-8.6
France	-9.4	5.8	3.1	0.5	0.9	1.5	8.5	10.7	10.0	-3.0	-2.8	-1.6	-10.5	-8.3	-6.1
Italy	-9.9	4.1	2.8	-0.1	0.7	1.0	9.9	11.6	11.1	2.9	3.1	2.9	-10.8	-7.8	-6.0
Cyprus	-6.2	3.7	3.0	-0.9	0.9	1.3	8.2	7.8	7.2	-10.4	-10.1	-9.9	-6.1	-2.3	-2.3
Latvia	-5.6	4.9	3.5	0.3	1.3	1.8	8.3	8.0	7.5	2.3	1.2	0.1	-7.4	-3.5	-3.3
Lithuania	-2.2	3.0	2.6	1.3	1.5	1.7	8.9	8.0	6.9	4.6	3.7	2.9	-8.4	-6.0	-2.8
Luxembourg	-4.5	3.9	2.7	0.2	1.5	1.8	6.6	7.1	7.1	0.8	1.2	1.8	-5.1	-1.3	-1.1
Malta	-7.3	3.0	6.2	0.8	1.3	1.6	5.1	4.7	4.1	0.5	0.1	1.4	-9.4	-6.3	-3.9
Netherlands	-5.3	2.2	1.9	1.1	1.3	1.4	4.4	6.4	6.1	8.4	8.0	7.9	-7.2	-5.7	-3.8
Austria	-7.1	4.1	2.5	1.5	1.7	1.7	5.5	5.1	4.9	2.3	2.9	3.2	-9.6	-6.4	-3.7
Portugal	-9.3	5.4	3.5	-0.1	0.9	1.2	8.0	7.7	6.6	-0.9	-0.5	-0.5	-7.3	-4.5	-3.0
Slovenia	-7.1	5.1	3.8	0.0	0.9	1.8	5.0	4.8	4.4	5.0	4.4	3.1	-8.7	-6.4	-5.1
Slovakia	-7.5	4.7	4.3	2.0	0.7	1.4	6.9	7.8	7.1	-3.1	-1.6	-0.9	-9.6	-7.9	-6.0
Finland	-4.3	2.9	2.2	0.4	1.1	1.4	7.9	7.7	7.4	-1.5	-1.2	-1.7	-7.6	-4.8	-3.4
Euro area	**-7.8**	**4.2**	**3.0**	**0.3**	**1.1**	**1.3**	**8.3**	**9.4**	**8.9**	**2.6**	**2.6**	**2.8**	**-8.8**	**-6.4**	**-4.7**
Bulgaria	-5.1	2.6	3.7	1.2	1.4	1.8	5.8	5.6	5.0	3.5	4.0	4.4	-3.0	-3.0	-1.4
Czechia	-6.9	3.1	4.5	3.4	2.3	2.0	2.7	3.3	3.2	-2.3	-2.0	-1.5	-6.2	-4.7	-3.7
Denmark	-3.9	3.5	2.4	0.3	1.1	1.3	6.1	5.8	5.5	6.7	6.8	7.2	-4.2	-2.5	-1.9
Croatia	-9.6	5.7	3.7	0.1	1.2	1.5	7.7	7.5	6.9	-1.7	-0.4	0.3	-6.5	-2.8	-3.2
Hungary	-6.4	4.0	4.5	3.4	3.3	3.0	4.4	4.4	3.9	-1.1	-0.3	-0.3	-8.4	-5.4	-4.3
Poland	-3.6	3.3	3.5	3.6	2.0	3.1	4.0	5.3	4.1	1.8	1.5	1.1	-8.8	-4.2	-3.0
Romania	-5.2	3.3	3.8	2.5	2.5	2.4	5.9	6.2	5.1	-4.6	-4.8	-4.9	-10.3	-11.3	-12.5
Sweden	-3.4	3.3	2.4	0.6	0.8	1.3	8.8	9.2	8.1	4.4	3.9	4.0	-3.9	-2.5	-1.4
EU	**-7.4**	**4.1**	**3.0**	**0.7**	**1.3**	**1.5**	**7.7**	**8.6**	**8.0**	**2.5**	**2.5**	**2.7**	**-8.4**	**-6.1**	**-4.5**
United Kingdom	-10.3	3.3	2.1	0.9	2.3	2.9	5.0	7.3	6.2	-3.1	-2.9	-2.7	-13.4	-9.0	-7.6
China	**2.1**	**7.3**	**5.6**	:	:	:	:	:	:	:	:	:	:	:	:
Japan	-5.5	2.7	0.9	0.1	0.1	0.3	3.1	2.9	2.7	2.3	2.8	2.9	-13.9	-5.6	-3.5
United States	-4.6	3.7	2.5	1.1	1.6	1.8	7.7	6.2	5.4	-3.0	-3.4	-3.2	-15.3	-6.9	-4.7
World	-4.3	4.6	3.6	:	:	:	:	:	:	:	:	:	:	:	:

Overview of the autumn 2020 Source EU Commission

Besides the dramatic effects on the health of EU citizens, the restrictions imposed by all of the EU Members States in order to limit the spread of the pandemic had a significant impact on all of the economic indicators. Production and trade fell sharply in almost every sector of the economy (from tourism to construction, from manufacturing to aerospace, from transport to culture, etc.) unemployment reached considerable heights while household spending and private investments dropped

180 *European Economic Forecast* (Autumn 2020), European Economy – Institutional Paper, 136 (November 2020)

considerably. The high level of uncertainty linked to the current crisis does not allow for the making of precise and correct predictions about the future of the European economy as the recovery will mostly depend on the dynamics of the pandemic's evolution.

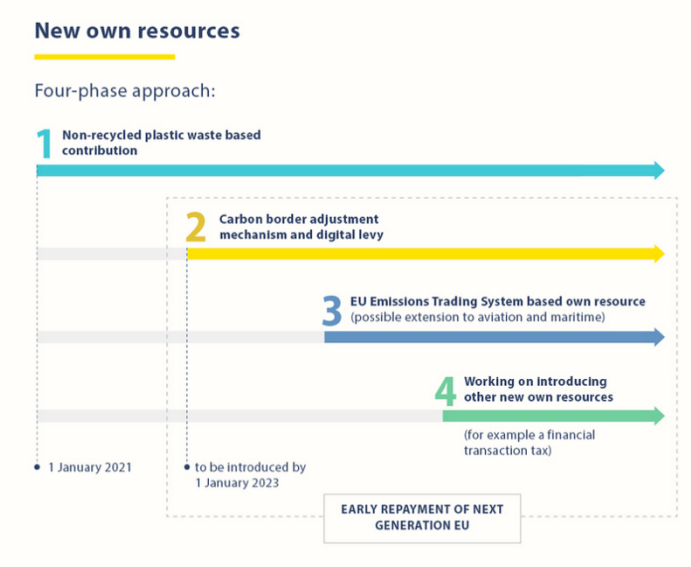
To tackle the severe and unprecedented effects of the socio-economic crisis, the EU adopted an ambitious plan for a swift and solid recovery during a special meeting of the European Council on 21 July 2020. The plan consists of a package that combines the future Multiannual Financial Framework (MFF) 2021-27 of EUR 1,074,3 billion with a temporary recovery instrument named, Next Generation EU (NGEU) of EUR 750 billion. To guarantee the sustainability and the impact of recovery measures, the MFF and NGEU have been designed in such a way as to boost an ambitious project where green and digital transitions go hand in hand to increase Europe's competitiveness, resilience and to improve its position as a global player.[181]

The European Recovery Plan contains measures for EUR 1.8 trillion and it sets the stage for the initiatives that will be adopted by the EU in the coming months. In this framework, particular emphasis is placed on those actions aimed at accelerating the twin green and digital transitions, as mentioned by President of the European Commission Ursula von der Leyen in her State of the Union address of the 16 September last.

As described in the section above, the Recovery Plan entails a combination of resources from the Multiannual Financial Framework (MFF) with a temporary recovery instrument named Next Generation EU (NGEU)[182]. This is an historical moment for the European Union, as for the first time the European Commission, thanks to the backup of EU Member States, will issue bonds on the financial markets for Nest Generation EU on this scale. The debt will be reimbursed through future EU budgets between 2028 and 2058. In order to make this possible, the EU decided to

[181] COM(2020) 456 final, *Europe's moment: Repair and Prepare for the Next Generation*, 2020.
[182] Negotiations on the adoption of the new MFF took longer than usual and the agreement was reached only in December 2020.

temporarily increase its own resource ceiling[183] of 0.6% and it envisages proposing a series of new own resources (i.e. Emission Trading Scheme, Carbon Border Adjustment Mechanism, digital tax on big tech companies). Specifically, the funding from NGEU shall be used to support projects in Member States tailored to their specific needs while being aligned with wider European objectives. The money will be channelled to EU programmes to finance a fast recovery focused on the twin digital and green transition.



EU new own resources. Source: European Council

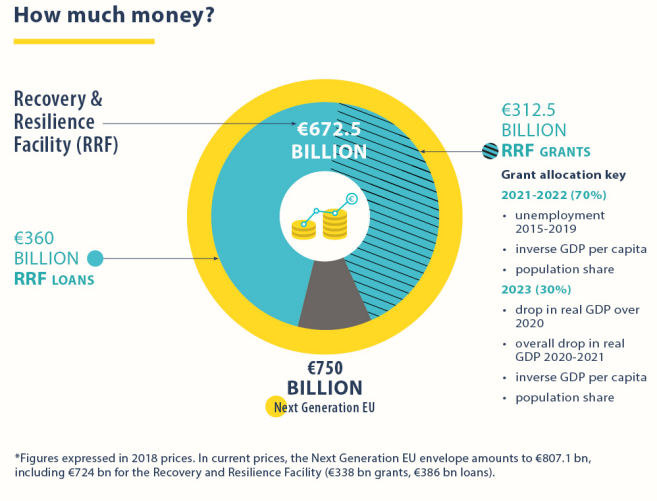
In such a scenario, the EU Commission wants to seize the moment to accelerate the twin green and digital transition to jumpstart a fast and steady recovery across the continent. Concerning digital transformation, the Recovery Plan foresees investments in areas already mentioned in the previous two sections of the current chapter. Indeed, digital recovery will rest on four main pillars: investments in more and better connectivity, the building of a stronger industrial and technological presence in strategic sectors of the digital supply chain, in particular strategic digital capacities and capabilities, a real data economy and fairer and easier business environment. This

[183] The Own Resource Decision is the legal text that sets the conditions to fund the EU budget. Usually set at 1.4% of GNI, the ceiling has been temporarily lifted to 2% of GNI.

means investments aimed at improving connectivity (in particular 5G) and at building the infrastructure both to increase the EU's autonomy and sovereignty and to manage future processes and applications for sectors such as health, education, transport, logistics, and media that are considered strategic for the future of EU competitiveness; the development of a stronger industrial and technological presence in strategic parts of the digital supply chain, such as AI, cybersecurity, data, secured communications, cloud infrastructure, 5G and 6G networks, supercomputers, quantum computers, block-chain in order to reaffirm EU tech sovereignty, the building a solid data economy through the creation of common European data spaces in key sectors and areas coupled with legislative actions on data sharing and governance to handle data sharing across Member States and sectors and to remove barriers to digital trade so as to make Europe fit and able to compete in the 21st global economy thus establishing the conditions for better access and control of industrial data (Data Act); the improvement of the legal framework for digital services with clear rules for online platforms, to prevent the abuse of market power and guarantee equal opportunities for SMEs (Digital Services Act). This also entails a reduction of the administrative burden for SMEs, the digitisation of public procurement by developing national e-procurement systems and platforms and a new Cybersecurity Strategy (Cybersecurity Strategy planned to be adopted in 2021) to increase cooperation, knowledge and capacity at EU level with the emergence of SMEs in the field. [184]

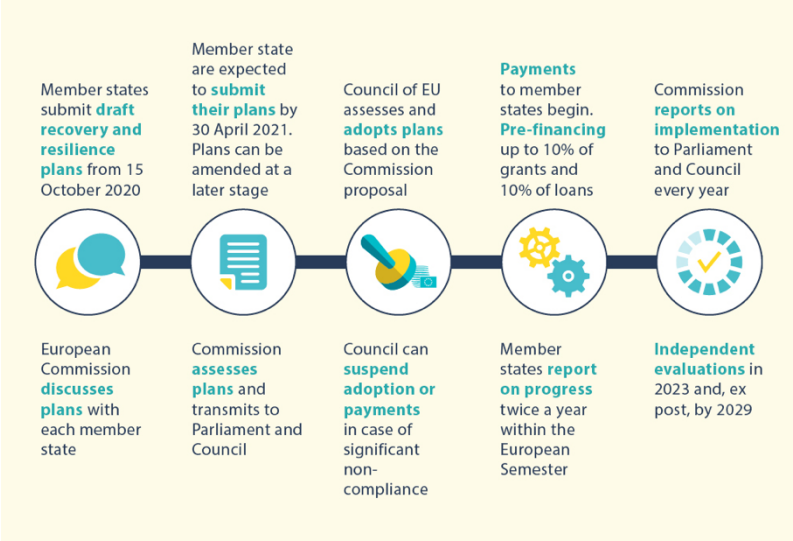
The core of Next Generation EU is the Recovery and Resilience Facility that will provide financial support to EU countries to mitigate the social and economic impact of the COVID-19 crisis.[185]

[184] COM(2020) 456 final, *Europe's moment: Repair and Prepare for the Next Generation*, 2020.
[185] https://www.consilium.europa.eu/en/infographics/20201006-recovery-resilience-rrf/



The Recovery & Resilience Facility. Source: EU Council

To obtain funding under the new RRF, Members States will have to submit their recovery and resilience plans centred on the two major policy objectives of the green and digital transitions that will be closely assessed by the EU institutions before being accepted, as briefly summarized in the infographic below.



The functioning of Recovery and Resilience Plans (Source: EU Council)

The *Annual Sustainable Growth Strategy* 2021 states that "The Recovery and Resilience Facility will be one of the main tools for the recovery, with an

unprecedented EUR 672.5 billion in loans (EUR 360 billion) and grants (EUR 312.5 billion) of frontloaded financial support in the crucial first years of the recovery. The Member States will encompass in their recovery and resilience plans their national agenda of reforms and investments designed in line with the EU policy objectives, centred around the green and digital transitions. The Facility will support Member States' efforts to strengthen their social and economic resilience effectively, and hence their economies' growth potential and job creation, thereby supporting the EU objectives."[186] It is worth mentioning that at least 20% of the resources of the plans must be invested in the EU digital transition.

To make the best of the Recovery and Resilience Facility, the Commission has identified seven main flagships to promote growth and job creation while favouring the twin transition.

Flagships under RRF

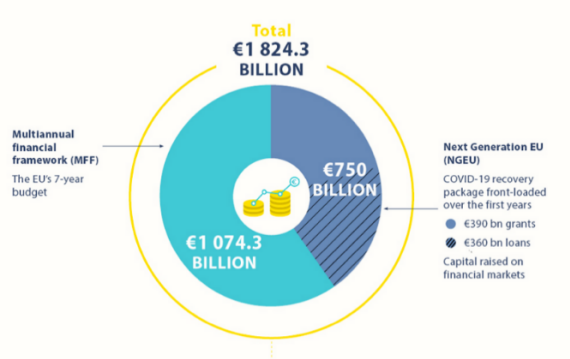
1. *Power up* – The frontloading of future-proof clean technologies and acceleration of the development and use of renewables.
2. *Renovate* – The improvement of energy efficiency of public and private buildings.
3. *Recharge and Refuel* – The promotion of future-proof clean technologies to accelerate the use of sustainable, accessible, and smart transport, charging and refuelling stations and extension of public transport.
4. *Connect* – The fast rollout of rapid broadband services to all regions and households, including fibre and 5G networks.
5. *Modernise* – The digitalisation of public administration and services, including judicial and healthcare systems.
6. *Scale-up* – The increase in European industrial data cloud capacities and the development of the most powerful, cutting edge, and sustainable processors.
7. *Reskill and upskill* – The adaptation of education systems to support digital skills and educational and vocational training for all ages.

[186] COM(2020) 575 final, *Annual Sustainable Growth Strategy 2021*, 2020.

The flagships have the objective of pooling resources to achieve coherent and harmonized policy objectives at EU level thereby increasing the convergence among Member State and consequently strengthening the Single Market. Considering the importance of the digital strategy to the Commission's agenda, it should come as no surprise that four out of the seven flagships (from four to seven) are directly related to digitalisation and digital transformation.[187] In this context, it is worth mentioning that "The European Council has called for further strengthening of the synergies between the use of EU and national funds as regards such key technological projects. The Recovery and Resilience Facility (RRF) Regulation and the Technical Support Instrument recognise the opportunity for developing Multi-Country Projects combining investments from several national recovery and resilience plans. Moreover, action should be planned for the longer term, seeking to ensure the mobilisation of investments from the EU budget, Member States and industry."[188] Among the multi-country digital projects discussed with the Member States we can indicatively cite a pan-European interconnected data processing infrastructure, low power trusted processors and other electronic components, 5G corridors, supercomputers and quantum computers, ultra-secure quantum communication infrastructure, security operation centres and connected public administration.
The agreement on the new Recovery package was finally reached on 10 December 2020 after some concerns expressed with regard to the draft Regulation on a general regime of conditionality for the protection of the EU budget were addressed.[189] The 2021-2027 multiannual financial framework (MFF) and the extraordinary recovery

[187] https://ec.europa.eu/commission/presscorner/detail/en/IP_20_1658
[188] COM(2021) 118 final, page 16.
[189] The discussion was delayed because of the opposition of Poland and Hungary to the rule of conditionality attached to the MFF package. According to this mechanism introduced by COM (2018)324 "whereby a generalized deficiency as regards the rule of law in a Member State affects or risks affecting the principles of sound financial management or the protection of the financial interests of the Union thus leading to measures such as the suspension and reduction of payments and commitment, and the prohibition to enter into new legal commitments." For further information, please see Maria Schinina, *Rule of law as integral part of the next MFF: to what extent and why?*, January 2020, available on: https://www.iee-ulb.eu/en/blog/news/rule-of-law-conditionality-integral-part-mff/.

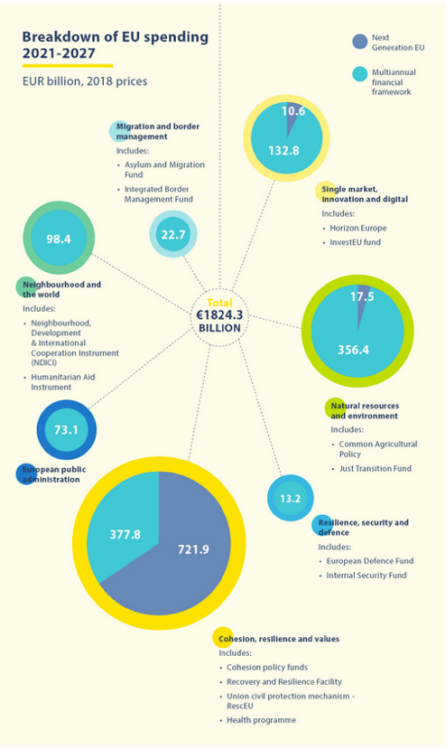
effort known as the Next Generation EU (NGEU) for a total of € 1,824 billion were subsequently adopted by the Parliament and the Council.



Source: European Council

For the period 2021-2027 the new MFF will be structured under 7 headings as described in the infographic on the right side of this page:

- Single market, Innovation and Digital
- Cohesion, Resilience and Values
- Natural Resources and Environment
- Migration and Border Management
- Security and Defence
- Neighbourhood and the World
- European Public Administration



For the purposes of this research, special attention will be placed on the first heading (Single market, Innovation and Digital) and the related programmes that "will contribute to the promotion of research, innovation and the digital transformation, as well as European Strategic Investments and action in favour of the Single Market and the

competitiveness of businesses, in particular SMEs." [190] The total financial envelope under the MFF 2021-27 will not exceed EUR 132,781 million but under the new NGEU some programmes will be further reinforced (see image below). Specifically, funding for digitalisation and digital transformation will be channelled through a series of different complementary programmes, as summarized in the table below.

EU-wide collective effort				**National, regional and local**		**Financial instrument**
Horizon Europe	**Digital Europe**	**CEF**	**EU4Health**	**Cohesion**	**Agriculture**	**Invest EU**
Investments in research and innovation	Strategic capacities (computing, data, testbeds) Advanced digital skills EU wide deployment	Broadband and 5G rollout Connecting communities	Data spaces for Health Telemedicine	Digital connectivity in white and grey areas Smart specialisation Digital skills	Making use of Big Data for CAP monitoring Broadband rollout in rural areas	Leverage private capital for investments in SMEs, research, digital, infrastructure, skills, etc.

Here below can be found a brief explanation of the main programmes that fall under direct management, namely Horizon Europe, Digital Europe, Connecting European Facility and EU4Health. The total financial envelope presented here already considers the final version of the MFF that takes into account the reinforcement of certain programmes thanks to the adoption of Next Generation EU.

- **Horizon Europe.** This programme is the successor of Horizon 2020 and it is the 9th framework programme for research and innovation. With a budget of €95.5 billion for the period 2021-27, it aims at increasing the science and innovation base of the European Union. In particular, the programme's scope is quite wide going from fundamental research to applied research and innovation.

[190] Special meeting of the European Council (17, 18, 19, 20 and 21 July 2020) – Conclusions, page 17. For further information, check https://www.consilium.europa.eu/media/45109/210720-euco-final-conclusions-en.pdf

- **Connecting Europe Facility.** With a budget of €28.7 billion, the Connecting Europe Facility (CEF) is a key EU funding instrument to promote growth, jobs and competitiveness through targeted infrastructure investment at European level. It supports the development of high performing, sustainable and efficiently interconnected trans-European networks in the fields of transport, energy, and digital services to facilitate free movement of persons, goods, capital and services thus contributing to foster greater economic, social and territorial cohesion.[191]
- **Digital Europe Programme**. As mentioned in the conclusion of the EU Council of July 21st, 2020, with a budget of €7.5 billion, "the Digital Europe programme will invest in key strategic digital capacities such as the EU's high-performance computing, artificial intelligence and cybersecurity. It will complement other instruments, notably Horizon Europe and CEF, in supporting the digital transformation of Europe.[192]
- **Eu4Health.** With a budget of €9.4 billion, it is the largest health programme ever in monetary terms. This programme is aimed at reinforcing the EU health sector by taking stock of the lessons learned from the Covid-19 crisis. In particular, the investments will serve the purpose of tackling cross-border health threats, strengthening health systems in the EU and at making medicines available and affordable in all EU members states.[193]

In addition, it is worth mentioning the new financial instrument InvestEU Fund. Building on the experience of the Investment Plan for Europe (also known as the Juncker plan) this new instrument "will act as a single EU investment support mechanism or internal action, replacing all existing financial instruments. Its overall objective is to support the policy objectives of the Union by mobilising public and

[191] For further information, please check the following website: https://ec.europa.eu/inea/en/connecting-europe-facility
[192] Special meeting of the European Council (17, 18, 19, 20and 21 July 2020) – Conclusions, page 20. For further information, check https://www.consilium.europa.eu/media/45109/210720-euco-final-conclusions-en.pdf
[193] For further information, check the following website: https://ec.europa.eu/health/funding/eu4health_fr

private investment within the EU that fulfil the criterion of additionality, thereby addressing market failures and sub-optimal investment situations that hamper the achievement of EU goals regarding sustainability, competitiveness and inclusive growth." [194] By using a EU budget guarantee (€38 billion), thanks to the leverage effect the instrument is expected to mobilize at least €650 billion in additional investments between 2021 and 2027.

[194] Special meeting of the European Council (17, 18, 19, 20 and 21 July 2020) – Conclusions, page 19. For further information, check https://www.consilium.europa.eu/media/45109/210720-euco-final-conclusions-en.pdf

5. Digitalising the construction sector in the EU perspective

"Our buildings generate 40% of our emissions. They need to become less wasteful, less expensive, and more sustainable. And we know that the construction sector can even be turned from a carbon source into a carbon sink, if organic building materials like wood and smart technologies like AI are applied.

I want NextGenerationEU to kickstart a European renovation wave and make our Union a leader in the circular economy.

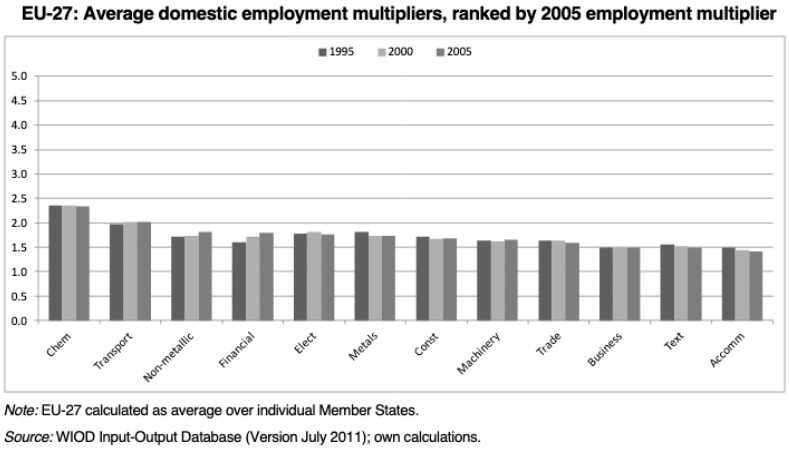
But this is not just an environmental or economic project: it needs to be a new cultural project for Europe. Every movement has its own look and feel. And we need to give our systemic change its own distinct aesthetic – to match style with sustainability. This is why we will set up a new European Bauhaus – a co-creation space where architects, artists, students, engineers, designers work together to make that happen"[195]

i. An introduction

The long excursus presented in the first section of this chapter is aimed at better framing the initiatives specifically those dedicated to the construction sector in the wider panorama of the EU digital strategy with a particular focus on what has been previously described "the journey of data". In fact, the EU is well aware of the importance of the construction sector for the EU economy, as testified by the words of Ursula von der Leyen in the recent SOTEU. In fact, talking about construction means talking about roads, railways, bridges, tunnels, concrete structures, special foundations, electrical works, water supply, wastewater treatment, works on maritime or river sites, offices, hospitals, hotels, schools, industrial buildings, individual dwellings, apartment blocks, social housing schemes and in housing.[196] As already

[195] State of the Union 2020, President von der Leyen's speech, 16 September 2020.
[196] *Key figures 2019*, *Construction activity in Europe*, edition 2020, FIEC.

mentioned in chapter 1 with more than 3 million enterprises and its 18 million workers, the construction sector represents about 9% of the EU GDP[197] and 43.2% of gross fixed capital formation in the EU27.[198] According to the 2012 study "Monitoring of sectoral employment" funded by the European Commission (DG Employment, Social Affairs and Inclusion) because of the multiplier effect one person working in the construction sector generates two further jobs in other sectors. [199]



Source: Monitoring of sectoral employment

These numbers are particularly interesting in light of public policy initiatives, as even a minor change in the sector can lead to impressive results in the overall economic fabric. In fact, dealing with the construction industry means dealing with a broad range of subjects such as energy savings, safety at work, environmental protection, technological innovation, standards, cybersecurity, women's participation, international cooperation, etc. In consequence, the number of Directorates-General are in charge of policies and programmes addressed to the sector is quite large. At the same time, because of its very horizontal nature, digitalisation – and in particular data

[197] *Digital Transformation in Transport, Construction, Energy, Government and Public Administration*, JRC Science for Policy Report, 2019, page 99.
[198] *Ibid.*
[199] *Study on Monitoring of sectoral employment*, final report, contract VC/2010/0064, page 182.

and AI – offers a wide range of opportunities both from the economic as well as from the societal standpoint. Digital technologies can indeed tackle a plethora of different problems from energy efficient to safety, from environmental issues to mobility to mention just a few.

Here below is presented a summary of the major changes due to the digitalisation process in the construction sector both for the value chain as well as for the construction market.

Short term	
Products	Value added services (*servitization*)
Traditional actors	New (digital) actors
Traditional business model	New business models
Standardised production	Customized production
Craftmanship	Industrial craftmanship
Analog tools	Digital tools (i.e., BIM, IoT, digital twin)
Analog materials & techniques	Smart materials & techniques
Medium/long term	
Manual labour	Automation
Building Construction	Lifecycle management of building
Fragmented actors	Integration of the value chain

Value Chain

Short term	
Building	Built environment
Isolated building	Connected building
Medium/long term	
Energy efficiency	Sustainability
Cost-efficiency	Quality of life
Building centric approach	User centric approach
Resource consumption of building	Resource production of building

Construction market

There's one last point probably worth mentioning at this stage. A few studies tend to consider the construction sector as a complex and dynamic system. In particular, in this sector projects and processes entail a variety of production factors, relations that are typical of complex systems.[200] In that regard, the use of data science will most probably open up new and unexpected horizons for the evolution of the sector in the years to come. As already mentioned in chapter 1, the adoption of an eco-system approach that relies on the use of data and AI technologies, that identifies potential bottlenecks and provides new and innovative solutions to improve efficiency in the entire system seems particularly promising. This eco-system" approach is therefore needed also for policy-making efforts as the very nature of digital technologies tend to generate spill-over effects from one sector to another, as extensively discussed by Haskel and Westlake.[201]

It is now time to move on to the analysis of the EC policy in the construction sector. Two DGs are responsible for the bulk of the initiatives in support of the digitalisation of the construction sector, namely DG GROW and DG CNECT. The following sections integrate the documentation that was kindly provided by the EU officials directly or indirectly responsible of the initiatives mentioned below with a series of interviews to have a better overall picture of the situation.

The European strategy for the sustainable competitiveness of the construction sector was defined in 2012 for the next decade[202]. The strategy focused on five key objectives:

a) stimulating favourable investment conditions
b) improving the human-capital basis of the construction sector

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[200] I am referring to the two studies Bertelsen, Sven, *Construction as a complex system* Proceedings for the 11th annual conference of the International Group for Lean Construction, 2003 and Vrijhoef, R. and Michael K. Tong *Understanding Construction as a Complex and Dynamic System: An Adaptive Network Approach",* 2004.

[201] Haskel, Jonathan, and Stian Westlake, *Capitalism without capital: the rise of intangible economy*. Oxford, 2018.

[202] COM(2012) 433, *Strategy for the sustainable competitiveness of the construction sector and its enterprises*, 2012.

c) improving resource efficiency, environmental performance, and business opportunities
d) strengthening the Internal Market for construction
e) fostering the global competitive position of EU construction enterprises.

The potential of the European construction sector was supposed to be largely developed through existing EU instruments and strategies. During 2013, the EC facilitated the development of a governance structure comprising a High Level Strategic Forum (HLF) and 5 Thematic Groups (TGs) to address the various actions presented in the Construction 2020 Action Plan. This bottom-up approach has provided Member States and stakeholders representatives with the opportunity to express their views with regards to the implementation of the various actions.
While maintaining the general direction of its 2012 strategy, the Commission is now readjusting future activities and widening the scope of construction related actions to the so-called built environment, that can be defined as the human-made space in which people live, work, and play on a day-to-day basis including buildings, parks, transport and infrastructure. It is an interdisciplinary field that addresses the design, construction, management, and use of man-made surroundings as an interrelated whole over time. The field is at the crossroad of economics, law, public health, security, management, social sciences, technology, and environmental sustainability, with people placed at the centre of its vision for the built environment.
In the long term, EU policies will deliver a framework for – and contribute to an improved built environment for people, providing high quality of life for all through comfortable, healthy, cost-effective urban or rural living, a high degree of mobility, a stimulating economic environment in an attractive, socially cohesive, future-proof, connected, decarbonised and sustainable setting.
The built environment is key in responding to the economic, environmental, and societal challenges the EU is facing, in particular jobs and growth, urbanisation, digitalisation, demographic changes, climate change, air pollution and nature conservation.

At Commission level, the built environment is currently addressed by a range of DGs and initiatives, each of which is considering specific aspects of improving the built environment and responding to specific policy goals (employment, urbanisation, regional development, competitiveness, internal market, energy efficiency, connectivity, mobility, climate adaptation, waste and water management, etc.).
A more integrated approach will be necessary at EU level to find the most resource-effective way to transform the EU built environment over the next decades. This will require a lot of investment and innovation from all relevant actors. A common EU vision for the built environment will facilitate an integrated approach. The Commission is exploring the best options to organise the work inside the Commission and with relevant stakeholders, to refine the vision and the pathways to steer this transformation in a resource-effective way.

ii. EU ongoing and future actions

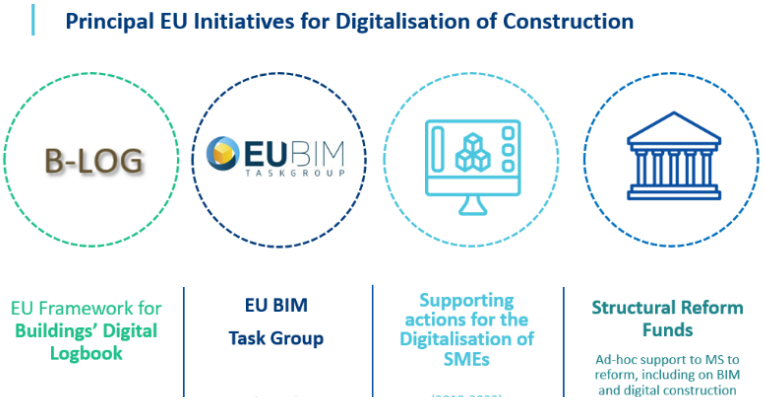
The EU Commission acknowledges that digitalisation allows informed decisions, predictions, and control across the lifecycle of built assets. It increases accuracy, transparency and safety in construction while reducing costs and resources. Robotics, drones, and 3D printing promise to revolutionise the way we build. Building Information Modelling (BIM) has become the synonym of digitalisation in construction, estimated to lead to cost savings of 8% in the design, engineering and construction phases and 7% in the operations phase. Opportunities are emerging from the combination and expansion of different technologies such as BIM with GIS (Georeferenced data), IoT, or laser scanning. Full-scale digitalisation in non-residential construction would lead to cost savings of 13%-21% in the engineering and construction phases and 10-17% in the operations phase.[203] As part of the Construction 2020 Strategy, DG GROW's strategy aims at accelerating the digitalisation of the sector by supporting the uptake of digital technologies and by

[203] *The Transformative Power of Building Information Modeling*, Castagnino, Rothballer, Renz, and Filitz, March 2018, Boston Consulting Group https://www.bcg.com/publications/2016/engineered-products-infrastructure-digital-transformative-power-building-information-modeling

empowering public entities to modernise as well as create demand for digitalisation through public procurement.

a) State of play

Here below are summarized some of the most relevant ongoing strategies.



1. *Building's Digital Logbook (BDL)*

   A building's digital logbook is a repository of data and information that accompanies the building throughout its lifecycle. Its purpose is to improve decision-making as well as transparency and trust. GROW is leading the development of an ''EU Framework for Building's Digital Logbook''. At the time of writing the European Commission was in the process of conducting consultations with over 150 stakeholders and experts and the mapping of more than 20 existing national initiatives with the aim of establishing a common definition and identifying gaps for the adoption of digital logbooks. The study[204] was finalised in December 2020 and it provides recommendations for follow up actions to spread the use of the BDL in the EU.

   In parallel, DG GROW collaborates with DG RTD to include funding for further research that will support the spread of BLD, notably under Cluster 6 of Horizon Europe. Additionally, the buildings' digital logbooks were explicitly mentioned

[204] *Study on the Development of European Union Framework for Digital Building Logbooks*, Dcember 2020.

in the new Circular Economy Action Plan as digital enablers of sustainable management of buildings throughout their lifecycle.[205]

2. *EU BIM Task Group (EUBIMTG)*

   Directive 2014/24/EU recommends the use of BIM in public procurement for construction. The maturity and adoption of BIM varies across different MS. The EUBIMTG was founded in 2016 to facilitate information exchange and common actions towards a unified EU-wide use of BIM and of digitalisation of construction. The EUBIMTG operates with the support of DG GROW. Currently, 25 EU MS are members, together with NO, UK, IS, MS are represented by public entities procuring for construction or making policy in the field, mainly being ministries (e.g., Ministries of Environment, Public Works, or Economic Affairs) and Agencies that manage public property. France is currently chairing the EUBIMTG supported by a Steering Committee. In 2017 the EUBIMTG created and published the Handbook for the introduction of BIM by the European Public Sector[206], which is a central reference point available in 20 languages. The Handbook provides governments and public sector clients with the main knowledge needed to lead the adoption of digital construction through a unified EU framework. Based on the Handbook, DG GROW supported training to 250 European public procurers in 10 different MS in the period 2018-2019. In addition, in collaboration with the EUBIMTG, DG GROW is currently developing an EU-wide method for conducting cost-benefit analysis for the use of BIM in public procurement, that will be shared through a dedicated guidebook for public procurers it is expect that it will finalised by May 2021. BIM is considered key to unlocking the infinite possibilities in the digitalisation of the built environment. Under the umbrella of the EUBIMTG thematic workshops on topics such as digital construction permits, digital twins, classification systems and other matters are continuously being organised.

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[205] DG GROW set up the European Construction Sector Observatory, to reassure evidence-based policy making. ECSO monitors the state of play in the sector in EU and MS level as well as digitalisation related national policy measures *(e.g. Plan Transition Numérique dans le Bâtiment)* and trends *(e.g.* drones and 3d printing*)*.

[206] For further information, visit the following website: http://www.eubim.eu/handbook/

3. *Supporting the digitalisation of construction SMEs*

   94% of EU construction enterprises had up to 9 employees in 2016. This is one principal characteristic of the sector, often linked to challenges such as the low adoption of digitalization[207] and investment in R&I, low rates of upskilling and difficulties in attracting talent and a younger workforce. DG GROW also carried out the study *Supporting digitalisation of the construction sector and SMEs* which analysed the state of play and the gaps and came up with recommended actions to support the digitalisation of the sector focusing on SMEs and micro-enterprises. In addition, it is currently developing a further two of the recommended actions expected to be implemented in the period 2021-2022. The first action concerns the Digital maturity scan and guiding interactive handbook for managers of construction SMEs that will enable them to assess the state of digitalisation of their enterprise and receive guidance on the steps to take through a mobile/tablet App. The analysis and proposals will be focused on software and storage, equipment, standards and regulations. The platform or app will also offer space for sharing and exchanging information on best practices, Q&A, contacts, and material inventory. The second action, directly linked to the first, consists in the training of SME managers and the training of trainers in the MS, based on the above-mentioned material.

4. *Ad-hoc support to Member States*

   On demand, support is given to MS to develop and enhance their national BIM strategies through projects supported by the Structural Reform Support Service that is currently managed by DG REFORM. DG GROW is providing expertise, guidance and is steering projects. These projects can be highly technical, such as the setup of an automatic BIM-based digital permit in Estonia, or strategic, such as the setting up of a national strategy for digitalisation of construction and BIM adoption in Bulgaria. Apart from being the central reference for technical expertise in the digitalisation of construction, EU-wide alignment of the

[207] See *Imagining construction's digital future,* McKinsey, June 2018.

initiatives in the field and maximum of absorption of the other work carried out at EU Level in the field has been secured through this mechanism: passing the recommendations for support to SMEs into national strategies, supporting MS in their participate in existing networks/ projects/initiatives and making use of the material that is already.

It is then worth mentioning a relevant point that concerns the design R&I policy for digitalisation of construction namely that DG GROW has been the reference point of policy and expertise in the area of construction and the built environment. Under the past Horizon2020 grants (coordinated by EASME[208]) funds have been allocated to projects that support the adoption of BIM (BIMplement, SPHERE and BIM Speed) testing the combination of BIM with energy efficiency, renovation, skills etc.

In the context of the future Horizon Europe, DG Growth has proposed and co-drafted proposals on *Digitalisation of construction and buildings for circularity* under Cluster 4, to support data generation and systems for buildings' digital logbooks and *Destination: A new way to build* in Cluster 6 which described needs and orientations for disrupting technologies in construction such as 3D Printing, Scanning, BIM of different dimentions and maturity.
Moreover, DG ENER is currently leading the development of the SRI (Smart Readiness Indicator for smart buildings), which is an energy related indicator to rate the capability of buildings to adapt their operation to the comfort of the occupant, also optimizing energy efficiency and overall performance, and to adapt their operation in reaction to signals from the grid (energy flexibility).

[208] EASME is the Executive Agency for Small and Medium-sized Enterprises and it manages several EU programmes in the fields of SME support & innovation, environment, climate action, energy, and maritime affairs on behalf of the Commission, notably the calls under Horizon2020 designed by DG GROW.

b) Planning for the future: Digitalising the EU Built Environment

The Strategy for a Sustainable Built Environment is being built through a year of collaboration between 14 DGs to integrate Commission policies affecting the construction, buildings and infrastructures, along a lifecycle approach to policy making. The Strategy was announced in the new Circular Economy Action Plan, the Industrial Strategy and the SME Strategy.
The Strategy rests on 4 pillars of action for construction, buildings, and infrastructure: climate neutrality, skills, finance and Digitalization. Under the cluster on Digitalisation the following actions are proposed:

1. Support at full speed for, EU-wide implementation of Building Digital Logbooks under a common EU Framework based on the action recommendations of the ongoing study. Implementation of the recommended actions, in the short-term. Expansion of the logbooks to other types of assets (large-scale infrastructure) and connection with city-level digital twins in the medium term.
2. Make BIM of high maturity the norm in all MS, that entails actions such as:
    a. keep supporting the EUBIMTG to develop and implement recommendations on Open BIM, handling of data and dependency on software providers, Standardisation, Classification, Data dictionaries etc. that will guarantee that EU public authorities of all sizes will get on board with digitalisation in a common European and safe way.
    b. Providing ad-hoc support to MS though SRSS (or another new and dedicated instrument of the same ad-hoc nature and EC involvement) to normalise the existence of national strategies for digital construction, modernisation of their public procurement in the built environment and creation of systems that automatise processes (ex. BIM enabled digital permits, BIM enabled digital logbooks, semi-automatic controls, BIM + GIS).
    c. Defining, measuring and assessing European targets and levels of maturity on BIM and digital construction for the public sector and

benchmarking to accomplish according to these levels. Among the points to be assessed: the existence of national vision, digital permit, logbook, BIM in procurement, etc.

3. Support full digitalisation of building permits. Right now, about 1/3 of EU MS have digital building permits, 1/3 completely paper based and the rest are at an hybrid state where some parts of the process are digital. The recent lockdown and social distancing measures have shown that a digital permitting system would allow an almost un-disturbed flow of incoming requests and issue of permits, and therefore a quicker pick up by the construction activity. This occasion is an opportunity to accelerate the transition to fully digital permits.
   In an approach similar to BIM above, the Commission intends to:

   a. Support and benefit from bottom-up initiatives already in place, like the recently-set up European Network of Digital Building Permits (EUnet4BDP) of public authorities (EE, PT, ES, NL, DE, FR) and academia (NL, IT, SL, ES, SE, DE, BE, UK) to share good practices and efforts and develop a unified EU Framework for digital permitting in the built environment. Similarly to the funding given to other projects such as DigiPLACE[209], the Commission is thinking that EUnet4BDP could be supported by a grant to deliver a Framework for digital permits in the EU

   b. Support national efforts to set up the digital infrastructure needed to introduce digital permits, or enhance existing systems already in place (e.g., digital verification of compliance with building regulations) through SRSS or similar instrument.

4. Support the SMEs in the construction ecosystem to engage in innovation and digitalisation by adopting mainstream technologies (e.g. BIM level 3 and 4 of

[209] An extensive description of this project will be provided at the end of the current chapter.

collaboration and of multiple dimensions) together with the use of drones, 3D printing, laser scanning and others. In addition, actions aimed at establishing dialogue, matchmakings and collaboration between traditional enterprises operating in the built environment and start-ups, digital companies which enter the construction and city development field are foreseen.

c) The renovation wave

The purporse of the Renovation Wave launched by the EU Commission in October 2020 is to improve the energy performance of buildings through the renovation of buildings. In accordance with the EU's vision, 10 years from now European buildings will "look remarkably different. In particular, "buildings will be the microcosms of a more resilient, greener and digitalised society, operating in a circular system by reducing energy needs, waste generation and emissions at every point and reusing what is needed."[210]

As already mentioned in the last SOTEU by President Von der Leyen, "buildings are responsible for about 40% of the EU's energy consumption, and 36% of greenhouse gas emissions from energy." However, "only 1% of buildings undergo energy efficient renovation every year, so effective action is crucial to making Europe climate-neutral by 2050." [211] Therefore, the EU envisages exploiting the potential of renovation in order to "rethink, redesign and modernise our buildings to make them fit for a greener and digital society and to sustain economic recovery"[212] especially in the aftermath of the COVID-19 crisis, and reach an objective of 35 million building units renovated by 2030.

In this context, the incorporation of smart technologies and ICT in buildings is of paramount importance in facing the challenges of green transformation. It will be

[210] COM(2020) 622 final, *A Renovation Wave for Europe – greening our buildings, creating jobs, improving lives*, 2020, page 25.
[211] *Renovation Wave: doubling the renovation rate to cut emissions, boost recovery and reduce energy poverty*, Press release, 14 October 2020, available here: https://ec.europa.eu/commission/presscorner/detail/en/IP_20_1835
[212] COM(2020) 622 final, *A Renovation Wave for Europe – greening our buildings, creating jobs, improving lives*, 14 October 2020, page 1.

highly beneficial both for energy performance, better comfort and well-being. Which is why among the areas of intervention and lead actions in the Renovation Wave "comprehensive and integrated renovation interventions for smart buildings, integration of renewable energy and enabling the measurement of current energy consumption"[213] are mentioned, this all requires an increasing level of digitalization (e.g. the use of the Smart Readiness Indicator[214]). Other measures such as the use of energy performance certificates (EPC) are considered important to guarantee a higher level of transparency on building performance. In that regard, the Commission is going to propose an update to the EPC framework, which will take into account emerging energy performance metering technologies. This point will require greater attention be paid to adopting of a "uniform EU machine-readable data format for the certificates and more stringent provisions on availability and accessibility of databases and federated digital repositories for EPCs."[215]

As already mentioned at the beginning of this section, the use of Digital Building Logbooks will contribute to the Renovation Wave. Specifically, the use of repositories of data that contain the "history" of the buildings through the integration of different sources such as EPCs, Building Renovation Passports[216], Smart Readiness Indicators, Level(s)[217], will facilitate a transparent exchange of information among stakeholders (owners, tenants, financial institutions, public authorities). The Commission intends also to "develop an EU Framework for digital permitting in the

[213] *Ibid*, page 6.
[214] This indicator has been developed by the Commission to to assess a building's ability to adapt to advanced technologies in terms of its performance capacity and energy flexibility.
[215] COM(2020) 622 final, *A Renovation Wave for Europe – greening our buildings, creating jobs, improving lives*, 14 October 2020, 8.
[216] A Building Renovation Passport can be defined as "a document – in electronic or paper format – outlining a long-term (up to 15 or 20 years) step-by-step renovation roadmap for a specific building, resulting from an on-site energy audit and fulfilling specific quality criteria and indicators8 established in dialogue with building owners". For further information, check the following website: http://www.bpie.eu/publication/building-renovation-passports-consumers-journey-to-a-better-home/
[217] As mentioned in the COM(2021) 622 final, "the Commission's recent Level(s) framework covers energy, material and water use, quality and value of buildings, health, comfort, resilience to climate change and life-cycle cost", see footnote 29.

built environment and establish a trusted scheme for certifying energy efficiency meters in buildings that can measure actual energy performance improvements."[218] As discussed in chapter 3) iii, the Commission deployed a series of instruments and initiatives such as Horizon Europe and, Digital Innovation Hubs, in order to favour the uptake of digital technologies in the sector, whose investment rate is still every low. In this sense, it is noteworthy that 70% of construction firms dedicate less than 1% of their revenues to digital and innovative projects, and the uptake in Building Information Modelling (BIM) as well as other technologies such as IoT, AI, robots and digital twin remains particularly low.[219] The digital twin of a building can be very helpful in providing information about real-time performance of that building and in preventing potential failures in the building system thus limiting the number of potential accidents. In addition, the use of BIM can enhance transparency, helping to limit potential waste or loss of money and other resources – which is why the EU Commission aims at promoting the use of BIM technology in public procurement. Finally, we let us remember the importance of digital industrial platforms, whose aim and modalities are described in the paragraph below. Digital industrial platforms are conceived to improve communication among stakeholders of one of more sectors and to offer them the opportunity to better collect, analyse and manage data with the ultimate purpose of providing new and innovative high added-value solutions to their customers.

However, the attention of the EU Commission is not limited to the current building stock, but it extends also to future stock. This is the meaning and the scope of the European Bauhaus initiative mentioned in the SOTEU in September 2020, the aim of which is to achieve a merging of style and sustainability thanks to the combination of innovation techniques and technologies with art and culture. In short, the European Bauhaus aims at nurturing "a new European aesthetic that combines performance with inventiveness." The initiative is intended to act as "as an incubator for

[218] COM(2020) 622 final, *A Renovation Wave for Europe – greening our buildings, creating jobs, improving lives*, 14 October 2020, page 16.
[219] *Ibid*. footnote 54.

innovation and creativity to drive sustainable design across Europe and beyond, which is also appealing and affordable for citizens […] to network practitioners from across disciplines and mobilise creative minds to reimagine how sustainable living could and should be in the future. Concretely, it will on the one hand bring together a network of experts such as "thinkers, planners, architects, entrepreneurs, students and citizens to develop sustainability in style" while on the other it will consist of real building projects across the EU. [220] Concerning the digital aspect, the initiative will pay particular attention to the digital construction dimension, that is considered one of the crucial points of future buildings. It is acknowledged that "digitization is increasingly changing the way we think and act. In the future, houses, settlements, and cities will work and function better thanks to their "digital twin". In synthesis, "computer simulations will make it possible to improve design decisions in terms of resource efficiency, reusability or impact on the environment and local climate."[221] This specific aspect will be reflected among others in future calls for proposals under the relevant programmes of the new Multi-Annual Financial Framework. The initiative will be rolled out in three different phases: "design" to prepare the ground for future calls through a broad and inclusive participatory process to co-design the new calls up to the summer of 2021, "delivery" of transformative projects as of the second half of 2021 and "diffusion" through the establishment in 2022 of a series of five Bauhaus in the EU.

iii. DEI and the construction sector

The EU launched the Digitising European Industry initiative more than 2 years ago. Part of the initiative is to look at the supply side of digital technologies: the development of technology building blocks via Partnerships and the building of the digital industrial platforms of the future.

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[220] *Ibid*. page 19-20.
[221] *A New European Bauhaus: op-ed article by Ursula von der Leyen,* President of the European Commission, October 2020, available on https://ec.europa.eu/commission/presscorner/detail/en/AC_20_1916

In 2016-17, a working group investigated building these digital industrial platforms of the future. It recognised that platforms are typically like operating systems operating between sensors, devices, machines on the one hand, and applications on the other hand. Their roles can be quite heterogeneous: from data integration, via acting as development environments, to connecting communities.

The working group also made recommendations on which industrial sectors to focus on. The manufacturing, agriculture, and health sectors had been included from the start. The working group did not consider the energy sector, but thanks to the interest of DG ENER, joint work programme topics were defined for the energy sector. The construction sector showed a clear interest in being included in the list of sectors as well. However, this interest was expressed too late to be included in the working group report at the same level as the other sectors.

The Commission took the working group recommendations into account for the definition of the current ICT Work Programme. There are Platforms and Pilot topics defined for the energy, manufacturing, health, and agriculture sectors.

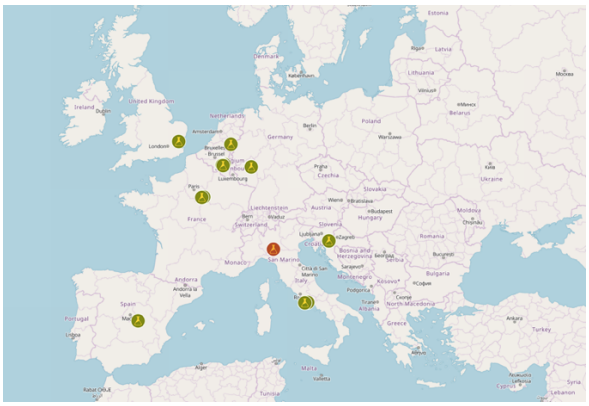
As part of the Digitising Europe Initiative DG CNECT has allocated a grant to construction stakeholders for the DigiPLACE project to develop a framework for a digital industrial platform for construction. DigiPLACE is aimed at defining a Reference Architecture Framework for digital construction platform based on an EU-wide consensus involving a large community of stakeholders, resulting in a strategic roadmap for successful implementation of this architecture. The preparatory action can at a later stage be followed up by a proper topic on a digital platform for the construction sector. This project will be discussed in greater detail in the section below.

Concerning the future Horizon Europe, DG CNECT envisages proposing calls under several clusters of Pillar II (Global Challenges and Industrial Competitiveness) on subjects such as Breakthrough innovations in techniques for exploring construction sites, for full automation of on-site assembly and prefabricated components, new business models, approaches and services for renovation financing, enhancement of construction skills, engagement of buildings occupants and other market actors, new

materials, techniques and methods of construction, operations and maintenance of infrastructures, ensuring reliable network availability and full life-cycle approach.

a) Case study: the DigiPLACE project

As extensively discussed in the previous sections, "the construction sector is a key driver for the economy, but it is one of the poorest performers in terms of productivity and innovation."[222] In this regard, digitalisation may bring enormous benefits in terms of higher productivity and profitability. The EU-funded project DigiPLACE is meant to "create a common ecosystem of innovation, standardisation and commerce to increase the construction sector's productivity and the quality of end products' in terms of buildings and infrastructure" and it will also "investigate what kind of digital transformation might improve productivity and efficiency."[223] The project began on 1 September 2019 and it is supposed to end on 31 May 2021. It has a budget of EUR 999,132.50 and it is funded under the call for proposal DT-ICT-12-2019 -Digital Platforms/Horizontal activities[224] of Horizon 2020. DigiPLACE is coordinated by the Polytechnic University of Milan and it brings together a relevant number of stakeholders (19 partners + 7 Linked Third Parties) with a wide EU coverage (11 countries, as shown in the image below).



Source: Cordis

[222] https://cordis.europa.eu/project/id/856943
[223] *Ibid.*
[224] For further details on the call, check the CORDIS website: https://cordis.europa.eu/programme/id/H2020_DT-ICT-13-2019

As mentioned on the official website, "DigiPLACE is a framework for the development of future digital platforms as common ecosystems for digital services that will support innovation, commerce, etc." Specifically, the project aims at defining "a Reference Architecture Framework (RAF) for a digital construction platform based on an EU-wide consensus involving a large community of stakeholders, resulting in a strategic roadmap for successful implementation of this architecture."[225] In general terms, the project aims at addressing the needs of the platform economy and the "platformization" trend in the construction sector, which is the result of a deeper penetration and adoption of digital technologies at several levels.

As discussed in the context of a recent interview with Dr. Claudio Mirarchi from Polytechnic of Milan, DigiPLACE originated from the need to assess first and foremost whether the need of an EU digital industrial platform for the construction sector was there and to subsequently define a reference architecture for such a platform by considering all the potential needs it might serve. At that time, several national initiatives already existed at national level such as Kroqi in France and Innovance in Italy. However, the scope of the project is to go beyond the national boundaries and set the stage for the launch of a platform at EU level that will favour higher harmonization among national initiatives by adopting a common EU vision, thus reducing the risk of further fragmentation where the level is already high compared to other sectors as discussed in chapter 3. In fact, despite representing an important step toward digital construction, national initiatives are only limited in scope as they are mainly addressed to national players, as testified by the fact that they are monolingual in some cases. In that regard, the project wants to build a common framework and integrate the national initiatives by adopting a common approach that can bring substantial benefits to market players by giving them the chance to extend their reach beyond their national boundaries.

[225] Detailed information is available on the official website at the following link: https://www.digiplaceproject.eu/about

From the beginning of the project, further issues became apparent such as the need to adopt common standards for data transfer and exchange, the importance of identifying and overcoming potential barriers to digitalisation, especially among SMEs and, mostly importantly, to determine what such a platform should look like to bring significant added value to the players in the construction sector in the EU.
The project is highly articulated, and it is structured in several work packages with different tasks and objectives. Some tasks are dedicated to a comparative analysis of existing platforms both in construction as well as in those sectors where strategic initiatives around platform development has already been defined, such as agriculture and manufacturing, in order to gather relevant knowledge to be used when defining the fundamentals of the RAF. One of the work packages is focused on the technical and social barriers that prevent the widespread and capillary adoption of digital technologies and techniques in the construction sector. A few factors have been identified like the unique characteristics of products and processes, the temporary nature of building projects and, in turn, value chains, a "cultural" resistance to change which is also due to a lack of adequate skills, and weak market incentives. However, possible mitigating measures to address the abovementioned problems can be introduced such as the adoption of common standards, strengthened educational and training paths as well as potential regulatory top-down initiatives that will gradually push the sector towards a higher level of digitalisation.
As underlined by Dr. Mirarchi, during the analysis particular attention was placed on the importance and the role of SMEs to ensure that they will benefit from the results of the project. Entry barriers can be particularly onerous for SMEs because of the high cost of the upfront investment and the uncertainty in terms of the return on that investment. Therefore, a comprehensive assessment on the SMEs level of digitalisation, the systems currently adopted as well as needs and requirements had to be taken into account right from the early phases of the project.
The Reference Architecture Framework (RAF) identified and developed within the framework of the project draws inspiration from a number of existing reference architectures that have been carefully identified and analysed in one of the work

packages. More specifically, the RAF is conceived as an aggregate of different architectures that can serve a variety of purposes in line with the different needs of end users, as described in the paragraph below. It is worth noticing that for each of them further development on the technical and business side will be required.
Firstly, the future platform can act as a marketplace to connect potential buyers and sellers and favouring market transactions among parties. Specifically, it will serve the purpose of aggregating and favouring the exchange of different products, services and solutions targeted at different customers or industry segments through a search mechanism that will make it easier for the customers to satisfy their demand.
Secondly, the platform will work as a repository of data coming from a wide array of actors and stakeholders in the value chain. In this sense, the aggregation of data coming from different sources looks particularly promising for the identification of new data-driven solutions through machine learning and other AI techniques that might bring huge benefits to the sector at different levels, as already mentioned above (e.g., CO2 emission reduction, improvement of safety onsite, enhancement of processes, better logistics, etc.). In that sense, the platform will act as the forerunner to a future data space for construction, as described in chapter 3 ii a). Thirdly, the future platform will act also as an eProcurement tool, meaning that it will be used as a place for contracting authorities and companies to organize, manage and follow all the procedures necessary for public procurement to take place electronically.
Following this multi-architectural definition, it is worth mentioning that while the DigiPLACE RAF represents a comprehensive framework integrating all the identified functions, this does not indicate the need to have one single platform able to address all of these functions.
In terms of legacy, DigiPLACE already sketches a possible roadmap for the future use and exploitation of the project results. If we assume that the answer to the initial question about the need to have an EU level digital industrial platform for the construction sector is positive, then particular attention should be placed in identifying the next steps to enhance the adoption of the RAF by public and private actors in every corner of the EU. In this sense, a few recommendations have been

drafted in order to make it happen. First, it is strongly suggested that the collaboration among the members of the network involved in the project be maintain and further developed as it demonstrates how cooperation among different actors along the value chain can be highly beneficial to bringing substantial added value and, ultimately, to steering the phenomenon of digital transformation in a harmonized and inclusive way. Second, a certain number of large-scale pilot tests/projects need to be envisaged in order to deploy and test the RAF solutions for the different uses described above (i.e. marketplace, data-sharing, eProcurement). In this regard, other existing EU funded projects (e.g. healthcare, agri-food, mobility etc.) can be taken as an example especially because "pilot tests will be targeted, goal driven initiatives [that] will bring together stakeholders from both the supply side to the demand side, and contain all the technological and innovation elements, the tasks related to the use, application and deployment as well as the development, testing and integration activities."[226] The large-scale validation phase of pilot projects will help understand how to operate the system(s) in different sites, to test the scalability of heterogeneous devices and systems, and the interaction with a large number of real users. As an example, the large-scale pilots will be the place to further develop and test data ontologies, data sharing protocols, data libraries, standards, etc. Third, on the basis of the results of DigiPLACE and (potentially) the following pilots, particular emphasis shall be put on setting up effective knowledge-management mechanisms to transfer the knowledge developed in the context of publicly funded projects to a wider audience of stakeholders through capacity building and/or other training initiatives. Certainly, synergies with Digital Innovation Hubs and other programmes such as Digital Europe shall be envisaged in order to maximize the impact. Finally, the experience developed from such projects is an extraordinary source of information for policymakers to design and adopt new regulations that are better suited to the new digital context and with higher levels of awareness (i.e. regulations to strengthen the digital single market).

[226] Large Scale Pilots, Cordis EU research results, https://cordis.europa.eu/programme/id/H2020_IoT-01-2016

One question still needs to be answered. What will the governance of the European industrial platform for the construction sector be? Probably, no single answer exists for the time being. In the opinion of Dr. Mirarchi, the governance of the platform shall be designed in such a way as to optimize the use of resources for everybody. That would mean that the EU platform should become a public commodity open to every actor willing to make use of its services and contribute to its development. In other words, such platforms will act as an open ecosystem where other national public and proprietary platforms could easily connect and integrate provided that they respect the entry parameters transparently set out in the beginning for the use of the EU platform, not only at a technical level (e.g., standards, interoperability, common protocols, cybersecurity, data protection, etc.), but also for what concerns the respect of EU values as mentioned in the EU digital strategy (see chapter 4). By subscribing to the platform, the different users can benefit from an extended reach and access to a broader number of services/products. Reasonably, national public initiatives should also follow the same approach to avoid unnecessary duplications while maximizing the impact of public investment through an enhanced level of cooperation among EU, national and regional authorities. On the private perspective, software houses and players from the construction sector who have been pioneering the development of proprietary platforms and whose interest is to provide their customers with always better, innovative and highly customized solutions will be engaged from the early phases of the deployment/adoption because of their long-lasting technical expertise and their interest in having their common data environment integrated into a platform that can give them an extended market reach and higher business returns.

In short, the launch of the EU platform for the construction sector shall be the result of a public-private partnership approach that will guarantee the highest possible level of participation and higher inclusion. This has the potential to ensure a level playing field while limiting market failures especially in low-digitalized countries where the interest in investing in the launch and development of digital industrial platforms from the private sector might be limited because of the high risk of investment and

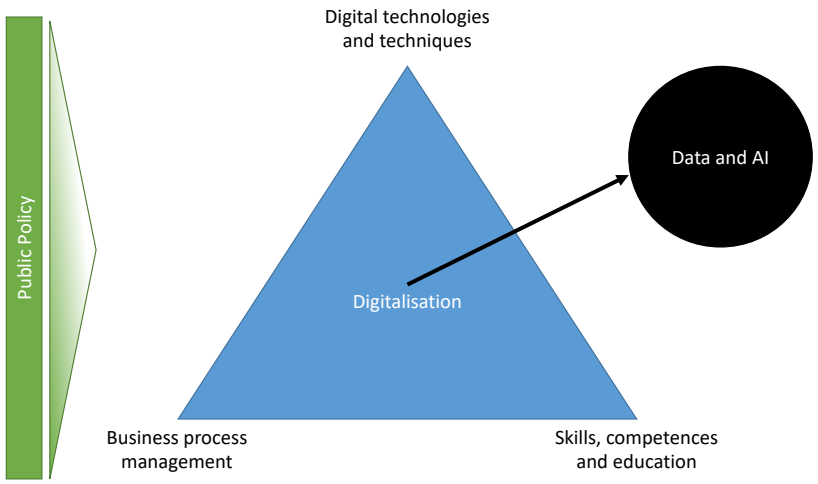
potentially low returns. In this sense, it would also have the advantage of reducing the level of fragmentation in the construction sector.

In conclusion, as the discussion on the governance mechanism is far from over, an enhanced dialogue among stakeholders shall be ensured in order to reach a common point of understanding that will preserve the competitiveness of the economic sector while keeping an eye on the societal challenges and potential drawbacks that will arise from digital transformation. In such a scenario, the EU still has a fundamental role to play in facilitating dialogue, by mediating different points of view and promoting new initiatives in order to reach the broadest possible consensus on the future of digital construction.

6. Conclusion

Now that we are approaching the end of the journey into digital construction, it is time to draw some conclusions on the nature of digital transformation in the construction sector based on what has been analysed in the previous chapters. For that purpose, I will start from the results of the Systematic Literature Review and from the three pillars during the assessment phase: 1) digital technologies and techniques, 2) business process management, 3) skills, competences and education. The future of digital construction will highly depend on the way these three deeply intertwined elements will evolve in the next years.

However, as extensively discussed all over the work, this is only part of the story. In particular, two additional elements are of paramount importance for the future evolution of the construction sector: data and AI, that lay at the very centre of the digital transformation, and the role of public policy on digitalisation, as exemplified in the image below.



As discussed in the previous chapters, data tend to be considered the real distinctive element of digital transformation in the construction sector. This point has been

solidly confirmed by the protagonists of the sector and by a plethora of case studies that were analysed in the context of the current research. Which is why digitalisation, in line also with the framework presented above, can be conceived as the use of the new digital technologies to extract relevant insights though the use of AI solutions and leveraging the power of information that stems from the collection, analysis and management of data to provide new solutions with a higher value added. [227] In such a short definition is contained the essence of digital transformation, which is not only a matter of technology but rather a mixture of elements where technology plays certainly a relevant role and where additional elements such as the expertise to collect, analyse and manage data is fundamental in order to shift the business model and embrace change. Because of the digitalisation trend, new business models are emerging thanks to the increasing adoption of data platforms that connect multiple actors of the value chain for different purposes, from matchmaking to data exchange, from marketplace to e-procurement, following the same trend of other sectors. The new data-driven business models in turn require new skills for the digital age both at the technical and managerial level. In particular, people inside organizations must cope with the needs of mastering the new digital technologies while at the same time organisations must adapt to the new paradigm in order to always be on the forefront of digital innovation. This progressive and steady penetration of IT into the construction industry will deeply change the way the sector will look like in the next years to such. As already mentioned in the introduction, in a 5-10 years' time we can expect the rise of new "hybrid" conglomerates that will bring together the expertise of the capital-intensive construction industry and IT and telematics knowledge to address the challenges and fulfil the market needs in the new digitalized society. Concerning the role of public policy, we are aware that governments are the most important client of the construction industry, therefore the process of digital transformation will be significantly influenced by the choices taken on this subject by

[227] *Digitalising the construction sector – Unleashing the potential of data with a value chain approach*, CECE, January 2019, page 11. This paragraph has been slightly modified in order to fit into the context of this conclusive chapter.

public authorities. This in turn can generate a significant impact on the economy as a whole because the construction sector, due to its size and structure, has one of the greatest economic knock-on effects thanks to the «multiplier effect». This reason pushed me to observe the phenomenon from an EU perspective in order to understand how the policies and programmes implemented by the EU institutions will influence the evolution of digital transformation in the years to come. In that regard, the EU wants to offer a third way *vis-à-vis* the US and the Chinese approach and to do so it intends to leverage on the EU values, a concept that stand for values such as privacy, security, safety, consumer protection and ethical standards in order to accompany the process of digital transformation. It is worth mentioning that there is a strong parallel between the framework presented above, which initially stem from the SRL and it was further consolidated by analysing interviews and case studies from the construction sector, and the initiatives of the EU. In particular, a strong focus is put on the importance of data and AI technologies and on their enabling power to trigger significant change while preserving the values enshrined in the EU building process. Therefore, most of the EU efforts regarding digitalisation are directed to investments in the development of new technologies, infrastructures and governance mechanisms to achieve the single market of data, investments in skills and competences for the digital age and the launch and implementation of European data spaces in strategic economic sectors in order to stimulate the market uptake of new data-solutions through an enhanced, fair and transparent exchange of data among sectors and countries in the EU. Following the success of the GDPR that swiftly became an example and reference for other countries and regions all over the world, the EU intends to accompany the entire process of digital transformation with a regulatory framework that will ensure the commitment to a social market economy that "requires technology to be deployed for wealth creation and the public good in equal measure".[228] While doubts may still arise about the success of the EU "third" way to

[228] Olaf Cramme*, Is Europe offering a Third Way in technology regulation?,* 19 February 2019. The same theme has been recently treated in a recent article published by Politico.eu on 21 April 2021 whose title is *Europe throws down gauntlet on AI with the new rulebook*.

the digital age in terms of competitiveness of the EU economy *vis-à-vis* other competitors, it is in certainly going to have an impact on the evolution of digital construction in the years to come, as extensively described the previous chapter. In particular, relevant initiatives such as the EU-funded project DigiPLACE are going to set the stage for further improvement in the sector by addressing the needs of the platform economy and the "platformization" trend, which is the result of a deeper penetration and adoption of digital technologies at several levels in order to increase the construction sector's productivity and the quality of end products in terms of buildings and infrastructure and, ultimately, to investigate what kind of digital transformation might improve productivity and efficiency.

In short, the current research was intended to provide the reader with a general framework to make sense of digital transformation in the construction sector from an EU perspective. It is worth adding that it may serve as a tool to sketch a potential roadmap for digital transformation by starting on the framework identified in the image above.

In that sense, any concerned player that has/wants to deal with digital construction should keep in mind the relevant elements listed above in order to orient a potential strategy:

- digital technologies and techniques, with a particular focus on data and AI;
- business process management, with specific attention on role of data science in developing new and innovative business models;
- skills, competences and education, both at technical and managerial/level, in order to face the complexity of digital transformation
- the role and the impact of public policy and regulations, that will significantly influence the way digitalisation of construction sector will evolve in the next years.

In conclusion, as already stated in the introductory chapter, this work sets out to shed some light on the nature and dynamics of digital construction knowing that it represents only the first brick in an ambitious project still "under construction".

Annex I. Articles for the Systematic Literature Review

Title	Authors	Journal	Article	Cluster
BIM – New rules of measurement ontology for construction cost estimation	Abanda, Kamsu-Foguem, Tah	Procedia Engineering, Volume 117, 2015, Pages 52-59	75	Cluster 7
Integration of BIM in Construction Management Education: An Overview of Pakistani Engineering Universities	Abbas, Ud Din, Farooqui	Procedia Engineering, Volume 145, 2016, Pages 151-157	31	Cluster 1
Take a Chance on Me? Construction Client's Perspectives on Risk Management	Abderisak, Lindahl	Procedia Economics and Finance, Volume 21, 2015, Pages 548-554	70	Cluster 6
A Review of the Application of Data Mining For Sustainable Construction in Nigeria	Aghimien, Aigbavboa, Oke	Energy Procedia, Volume 158, 2019, Pages 3240-3245	20	Cluster 12
Teaching construction sciences with the integration of BIM to undergraduate architecture students	Agirbas	Frontiers of Architectural Research, 2020	60	Cluster 1
Investigation of Document Management Systems in Small Size Construction Companies in Jordan	Ahmad, Bazlamit, Ayoush	Jordan, Procedia Engineering, Volume 182, 2017, Pages 3-9	46	Cluster 1
Designing out construction waste using BIM technology: Stakeholders' expectations for industry deployment	Akinade, Oyedele, Ajayi, Bilal, Alaka, Owolabi, Arawomo	Journal of Cleaner Production, Volume 180, 2018, Pages 375-385	16	Cluster 4

Deep Learning in the Construction Industry: A Review of Present Status and Future Innovations	Akinosho, Oyedele, Bilal, Ajayi, Delgado, Akinade, Ahmed	Journal of Building Engineering, 2020	82	Cluster 9
Exploring the role of building information modeling in construction safety through science mapping	Akram, Thaheem, Nasir, Ali, Khan	Safety Science, Volume 120, 2019, Pages 456-470	105	Cluster 13
Additive manufacturing: Technology, applications, markets, and opportunities for the built environment	Al Rashid, Alim Khan, Al-Ghamdi, Koç	Automation in Construction, Volume 118, 2020	104	Cluster 3
Industrial Revolution 4.0 in the construction industry: Challenges and opportunities for stakeholders	Alaloul, M.S. Liew, Zawawi, Kennedy	Ain Shams Engineering Journal, Volume 11, Issue 1, 2020, Pages 225-230	59	Cluster 14
The Current State of Research and Development Approach (R&D) in the Saudi Construction Industry	Alhammadi, Algahtany, D. Kashiwagi, Kenneth Sullivan, J. Kashiwagi	Procedia Engineering, Volume 145, 2016, Pages 1462-1469	139	Cluster 1
Environmental assessment of large-scale 3D printing in construction: A comparative study between cob and concrete	Alhumayani, Gomaa, Soebarto, Jabi	Journal of Cleaner Production, Volume 270, 2020	106	Cluster 3
A method for vertical adjustment of digital aerial photogrammetry data by using a high-quality digital terrain model	Ali-Sisto, Gopalakrishnan, Kukkonen, Savolainen, Packalen	International Journal of Applied Earth Observation and Geoinformation, Volume 84, 2020	6	Cluster 5

Novel Integration of Sustainable and Construction Decisions into the Design Bid Build Project Delivery Method Using BPMN	Ali, Badinelli	Procedia Engineering, Volume 145, 2016, Pages 164-171	133	Cluster 12
The Impact of Field Data Capturing Technologies on Automated Construction Project Progress Monitoring	Alizadehsalehi, Yitmen,	Procedia Engineering, Volume 161, 2016, Pages 97-103	36	Cluster 2
Development of functional geopolymers for water purification, and construction purposes	Alshaaer, El-Eswed, Yousef, Khalili, Rahier	Journal of Saudi Chemical Society, Volume 20, Supplement 1, 2016, Pages S85-S92	114	Cluster 0
BIM-based Applications of Metaheuristic Algorithms to Support the Decision-making Process: Uses in the Planning of Construction Site Layout	Amiri, Sardroud, García de Soto	Procedia Engineering, Volume 196, 2017, Pages 558-564	52	Cluster 7
Creating Shared Value in a Construction Project – A Case Study	Andelin, Karhu, Junnila	Procedia Economics and Finance, Volume 21, 2015, Pages 446-453,	67	Cluster 12
The Interface between Industrialized and Project Based Construction	Andersson, Lessing	Volume 196, 2017, Pages 220-227	108	Cluster 12
Latent Class Analysis for Highway Design and Construction Project Categorization	Antoine, Molenaar	Procedia Engineering, Volume 145, 2016, Pages 1314-1321	123	Cluster 12
Check and Monitoring of Condition of Concrete Slurry Wall, Jet-grouting and Frozen Soil Fences by	Arkhipov	Procedia Engineering, Volume 165, 2016, Pages 11-18	43	Cluster 11

Crosshole Sounding Method in Underground Construction				
Development of 3D-printable ultra-high performance fiber-reinforced concrete for digital construction	Arunothayan, Nematollahi, Ranade, Hau Bong, Sanjayan	Construction and Building Materials, Volume 257, 2020	101	Cluster 0
Advanced Virtual Reality Applications and Intelligent Agents for Construction Process Optimisation and Defect Prevention	Asgari, Rahimian	Procedia Engineering, Volume 196, 2017, Pages 1130-1137	57	Cluster 2
Analysis of the compactness and properties of the hardened state of mortars with recycling of construction and demolition waste (CDW)	Azevedo, Cecchin, Carmo, Silva, Campos, Shtrucka, Marvila, Monteiro	Journal of Materials Research and Technology, Volume 9, Issue 3, 2020, Pages 5942-5952	76	Cluster 0
Challenges of BIM for Construction Site Operations	Bargstädt	Procedia Engineering, Volume 117, 2015, Pages 52-59	25	Cluster 12
Investigating profitability performance of construction projects using big data_ A project analytics approach	Bilal, Oyedele, Kusimo, Owolabi, Akanbi, Ajayi, Akinade, Davila Delgado	Journal of Building Engineering, Volume 26, 2019	81	Cluster 14
Towards a semantic Construction Digital Twin_ Directions for future research	Boje, Guerriero, Kubicki, Rezgui	Automation in Construction, Volume 114, 2020	13	Cluster 14

Green BIM in Sustainable Infrastructure	Bonenberg, Wei	Procedia Manufacturing, Volume 3, 2015, Pages 1654-1659	118	Cluster 12
Automated processing of construction specifications to support inspection and quality control	Boukamp, Akinci	Automation in Construction, Volume 17, Issue 1, 2007, Pages 90-106	109	Cluster 8
A Review of Building Information Modelling for Construction in Developing Countries	Bui, Merschbrock, Munkvold	Procedia Engineering, Volume 164, 2016, Pages 487-494	40	Cluster 13
A process classification framework for defining and describing Digital Fabrication with Concrete	Buswell, Leal da Silva, Bos, Schipper, Lowke, Hack, Kloft, Mechtcherine, Wangler, Roussel	Cement and Concrete Research, Volume 134, 2020	1	Cluster 3
LOD Standardization for Construction Site Elements	Cassano, Trani	Procedia Engineering, Volume 196, 2017, Pages 1057-1064.	55	Cluster 13
Additive manufacturing as an enabling technology for digital construction: A perspective on Construction 4.0	Craveiro, Duarte, H. Bartolo, P.J. Bartolo	Automation in Construction, Volume 103, 2019, Pages 251-267.	111	Cluster 3
BIM, Augmented and Virtual Reality empowering Lean Construction Management: a project simulation game	Dallasega, Revolti, Christopher Sauer, Schulze, Rauch	Procedia Manufacturing, Volume 45, 2020, Pages 49-54.	78	Cluster 12

Robotics and automated systems in construction_ Understanding industry-specific challenges for adoption	Davila Delgado, Oyedele, Ajayi, Akanbi, Akinade, Bilal, Owolabi	Journal of Building Engineering, Volume 26, 2019	80	Cluster 1
Applications of additive manufacturing in the construction industry – A forward-looking review	Delgado Camacho, Clayton, O'Brien, Seepersad, Juenger, Ferron, Salamone	Automation in Construction, Volume 89, 2018, Pages 110-119	113	Cluster 3
Challenges and Thoughts on Risk Management and Control for the Group Construction of a Super-Long Tunnel by TBM	Deng	Engineering, Volume 4, Issue 1, 2018, Pages 112-122.	63	Cluster 11
Potential Applications of UAV along the Construction's Value Chain	Dupont, Chua, Tashrif, Abbott	Procedia Engineering, Volume 182, 2017, Pages 165-173	47	Cluster 13
A Lessons Learned Database Structure for Construction Companies	Eken, Bilgin, Dikmen, Birgonul	Procedia Engineering, Volume 123, 2015, Pages 135-144,	27	Cluster 4
Decision Making in Construction Management: AHP and Expert Choice Approach	Erdogan, Šaparauskas, Turskis	Procedia Engineering, Volume 172, 2017, Pages 270-276	45	Cluster 12
Estimating Industry 4.0 impact on job profiles and skills using text mining	Fareri, Fantoni, Chiarello, Coli, Binda	Computers in Industry, Volume 118, 2020	99	Cluster 9

A Lessons-learned System for Construction Project Management: A Preliminary Application	Ferrada, Núñez, Neyem, Serpell, Sepúlveda	Procedia - Social and Behavioral Sciences Volume 226, 2016, Pages 302-309	22	Cluster 1
Risk level reduction in construction sites: Towards a computer aided methodology â€“ A case study	Ferreira, Santos, Silva	Applied Computing and Informatics, Volume 15, Issue 2, 2019, Pages 136-143	64	Cluster 6
Productivity of digital fabrication in construction_ Cost and time analysis of a robotically built wall	García de Soto, Agustí-Juan, Hunhevicz, Joss, Graser, Habert, Adey	Automation in Construction, Volume 92, 2018, Pages 297-311	92	Cluster 3
Automated crack detection and measurement based on digital image correlation	Gehri, Mata-Falcón, Kaufmann	Construction and Building Materials, Volume 256, 2020	14	Cluster 5
A BIM-based Construction Supply Chain Framework for Monitoring Progress and Coordination of Site Activities	Getuli, Mastrolembo Ventura, Capone, Ciribini	Procedia Engineering, Volume 164, 2016, Pages 542-549	41	Cluster 12
BIM-based Code Checking for Construction Health and Safety	Getuli, Mastrolembo Ventura, Capone, Ciribini	Procedia Engineering, Volume 196, 2017, Pages 454-461	50	Cluster 7
Additive manufacturing technology and its implementation in construction as an eco-innovative solution	Ghaffar, Corker, Fan	Automation in Construction, Volume 93, 2018, Pages 1-11	10	Cluster 3

Digital engineering potential in addressing causes of construction accidents	Golizadeh, Hon, Drogemuller, Hosseini	Automation in Construction, Volume 95, 2018, Pages 284-295	117	Cluster 13
Building Information Modelling as an Opportunity and Risk for Stakeholders Involved in Construction Investment Process	Grzyl, Miszewska-Urbańska, Apollo	Procedia Engineering, Volume 196, 2017, Pages 1026-1033	53	Cluster 12
The Role of VDC Professionals in the Construction Industry	Gustafsson, Gluch, Gunnemark, Heinke, Engström	Procedia Economics and Finance, Volume 21, 2015, Pages 478-485	69	Cluster 1
Design and Application of a Digital Factory Model for Factory Restructuring	Hellmuth, Frohnmayer, Sulzmann	Procedia CIRP, Volume 91, 2020, Pages 158-163	74	Cluster 7
Evaluation of BIM-based LCA results for building design	Hollberg, Genova, Habert	Automation in Construction, Volume 109, 2020	115	Cluster 4
BIM and Safety Rules Based Automated Identification of Unsafe Design Factors in Construction	Hongling, Yantao, Weisheng, Yan	Procedia Engineering, Volume 164, 2016, Pages 467-472	39	Cluster 13
Do you need a blockchain in construction? Use case categories and decision framework for DLT design options	Hunhevicz, Hall	Advanced Engineering Informatics, Volume 45, 2020	90	Cluster 14
Survey data on digitalization of building procurement process by architectural firms in Abuja, Nigeria	Ibem, Akinola, Erebor, Tolani, Nwa-uwa	Data in Brief, Volume 20, 2018, Pages 1062-1067	79	Cluster 4

Survey of digital technologies in procurement of construction projects	Ibem, Laryea	Automation in Construction, Volume 46, 2014, Pages 11-21	119	Cluster 4
BIM-integrated management of occupational hazards in building construction and maintenance	J.P. Cortés-Pérez, A. Cortés-Pérez, Prieto-Muriel	Automation in Construction, Volume 113, 2020	95	Cluster 6
Using Mixed Reality for electrical construction design communication	Jad Chalhoub, Steven K. Ayer	Automation in Construction, Volume 86, 2018, Pages 1-10,	9	Cluster 7
Functional Assessment of BIM Methodology Based on Implementation in Design and Construction Company	Jankowski, Prokocki, Krzemiński	Procedia Engineering, Volume 111, 2015, Pages 351-355,	24	Cluster 7
4D BIM for Environmental Planning and Management	Jupp	Procedia Engineering, Volume 180, 2017, Pages 190-201	48	Cluster 4
New Boundary Spanners: Emerging Management Roles in Collaborative Construction Projects	Karrbom Gustavsson,	Procedia Economics and Finance, Volume 21, 2015, Pages 146-153,	65	Cluster 12
A Suitability Analysis of Precast Components for Standardized Bridge Construction in the United Kingdom	Kim, McGovern, Belsky, Middleton, Brilakis	Procedia Engineering, Volume 164, 2016, Pages 188-195,	37	Cluster 12
The application of PDA as mobile computing system on construction management	Kimoto, Endo, Iwashita, Fujiwara	Automation in Construction, Volume 14, Issue 4, 2005, Pages 500-511	122	Cluster 9

New System of Monitoring of a Condition of Cracks of Small Reinforced Concrete Bridge Constructions	Krakhmal'ny, Evtushenko, Krakhmal'naya,	Procedia Engineering, Volume 150, 2016, Pages 2369-2374	34	Cluster 2
The Potential of Decision Support Systems for More Sustainable and Intelligent Constructions: A Short Overview	Labonnote, Skaar, Rüther	Procedia Manufacturing, Volume 12, 2017, Pages 33-41	77	Cluster 12
Blockchain in the built environment and construction industry_ A systematic review, conceptual models and practical use cases	Li, Greenwood, Kassem	Automation in Construction, Volume 102, 2019, Pages 288-307	125	Cluster 14
An Internet of Things-enabled BIM platform for on-site assembly services in prefabricated construction	Li, Xue, Li, Hong, Shen,	Automation in Construction, Volume 89, 2018, Pages 146-161	124	Cluster 2
First generation microcapsule-based self-healing cementitious construction repair materials	Litina, Al-Tabbaa	Construction and Building Materials, Volume 255, 2020	100	Cluster 0
A digital twin-based approach for dynamic clamping and positioning of the flexible tooling system	Liu, Du, Zhou, Liu, Li, Feng	Procedia CIRP, Volume 80, 2019, Pages 746-749	72	Clustera 14
Towards sustainable construction: BIM-enabled design and planning of roof sheathing installation for prefabricated buildings	Liu, Sydora, Altaf, Han, Al-Hussein	Journal of Cleaner Production, Volume 235, 2019, Pages 1189-1201	126	Cluster 7
Creating a mindfulness to learn from errors: Enablers of rework containment and reduction in construction	Love	Developments in the Built Environment, Volume 1, 2020	86	Cluster 6

Hidden Reserves of Post-crisis Development of Construction Industry	Lukmanova, Yaskova	Procedia Engineering, Volume 165, 2016, Pages 1293-1299	44	Cluster 12
Coupled simulation of thermally active building systems to support a digital twin	Lydon, Caranovic, Hischier, Schlueter	Energy and Buildings, Volume 202, 2019	7	Cluster 3
Major Technologies for Safe Construction of High Earth-Rockfill Dams	Ma, Chi	Engineering, Volume 2, Issue 4, 2016, Pages 498-509	62	Cluster 11
Multi-disciplinary Discourse on Design-related Issues in Construction Site Meetings	Mäki	Procedia Economics and Finance, Volume 21, 2015, Pages 231-238	130	Cluster 12
Establishing relationships between structural data from close-range terrestrial digital photogrammetry and measurement while drilling data	Manzoor, Liaghat, Gustafson, Johansson, Schunnesson,	Engineering Geology, Volume 267, 2020	3	Cluster 5
Method of enhancing interlayer bond strength in construction scale 3D printing with mortar by effective bond area amplification	Marchment, Sanjayan, Xia	Materials & Design, Volume 169, 2019	4	Cluster 0
Management of construction Safety and Health Plans based on automated content analysis	Martínez-Rojas, Antolín, Salguero-Caparrós, Rubio-Romero	Automation in Construction, Volume 120, 2020	98	Cluster 6
A scientometric analysis and critical review of computer vision applications for construction	Martinez, Al-Hussein, Ahmad	Automation in Construction, Volume 107, 2019	127	Cluster 9

Simulation of labor evacuation: The case of housing construction projects	Marzouk, Al Daoor	HBRC Journal, Volume 14, Issue 2, 2018, Pages 198-206	19	Cluster 7
Ontology of BIM in a Construction Project Life Cycle	Matějka, Tomek	Procedia Engineering, Volume 196, 2017, Pages 1080-1087	56	Cluster 4
Generalising via the Case Studies and Adapting the Oil and Gas Industry's Project Execution Concepts to the Construction Industry	Mejlænder-Larsen	Procedia Economics and Finance, Volume 21, 2015, Pages 271-278	116	Cluster 12
Detection and geometric characterization of rock mass discontinuities using a 3D high-resolution digital outcrop model generated from RPAS imagery – Ormea rock slope, Italy	Menegoni, Giordan, Perotti, Tannant	Engineering Geology, Volume 252, 2019, Pages 145-163,	2	Cluster 5
Circumventing Obstacles in Digital Construction Design – A Workaround Theory Perspective	Merschbrock, Figueres-Munoz	Procedia Economics and Finance, Volume 21, 2015, Pages 247-255	128	Cluster 13
Solution Selection in Digital Construction Design – A Lazy User Theory Perspective	Merschbrock, Tollnes, Nordahl-Rolfsen,	Procedia Engineering, Volume 123, 2015, Pages 316-324,	28	Cluster 13
Automated Hardhat Detection for Construction Safety Applications	Mneymneh, Abbas, Khoury	Procedia Engineering, Volume 196, 2017, Pages 895-902	51	Cluster 5
A Construction Procurement Method to Achieve Sustainability in Modular Construction	Molavi, Barral	Procedia Engineering, Volume 145, 2016, Pages 1362-1369	33	Cluster 12

What did you learn from practice today? Exploring experiences from a Danish R&D effort in digital construction	Moum, Koch, Haugen	Advanced Engineering Informatics, Volume 23, Issue 3, 2009, Pages 229-242	129	Cluster 1
A New Robotic Spray Technology for Generative Manufacturing of Complex Concrete Structures Without Formwork	Neudecker, Bruns, Gerbers, Heyn, Dietrich, Dröder, Raatz, Kloft,	Procedia CIRP, Volume 43, 2016, Pages 333-338	103	Cluster 3
Factor-based big data and predictive analytics capability assessment tool for the construction industry	Ngo, Hwang, Zhang	Automation in Construction, Volume 110, 2020	94	Cluster 1
Pilot test of a tailored intervention to improve apprentice safety in small construction companies	Nielsen, Grytnes, Dyreborg	Safety Science, Volume 117, 2019, Pages 305-313	8	Cluster 6
Technologies for safety and health management in construction: Current use, implementation benefits and limitations, and adoption barriers	Nnaji, Karakhan	Journal of Building Engineering, Volume 29, 2020	131	Cluster 6
Acceptance of Construction Scheduling Visualizations: Bar-charts, Flowline-charts, Or Perhaps BIM?	Nordahl Rolfsen, Merschbrock	Procedia Engineering, Volume 164, 2016, Pages 558-566	42	Cluster 13
Optimization and mechanical-physical characterization of geopolymers with Construction and Demolition Waste (CDW) aggregates for construction products	Panizza, Natali, Garbin, Ducman, Tamburini	Construction and Building Materials, Volume 264, 2020	15	Cluster 0

Additive manufacturing in construction: A review on processes, applications, and digital planning methods	Paolini, Kollmannsberger, Rank	2019, Pages 1-11	89	Cluster 3
Flexible approach for construction process management under risk and uncertainty	Paslawski	Procedia Engineering, Volume 208, 2017, Pages 114-124	23	Cluster 14
Industry 4.0 as an enabler of proximity for construction supply chains_ A systematic literature review	Patrick Dallasega, Erwin Rauch, Christian Linder	Computers in Industry, Volume 99, 2018, Pages 205-225	112	Cluster 9
Blockchain technology_ Is it hype or real in the construction industry?	Perera, Nanayakkara, Rodrigo, Senaratne, Weinand	Journal of Industrial Information Integration, Volume 17, 2020	84	Cluster 10
Improving Socially Sustainable Design and Construction in Developing Countries	Pocock, Steckler, Hanzalova	Procedia Engineering, Volume 145, 2016, Pages 288-295	120	Cluster 12
Digital image reasoning for tracking excavation activities	Quiñones-Rozo, Hashash, Liu	Automation in Construction, Volume 17, Issue 5, 2008, Pages 608-622	91	Cluster 5
On-demand monitoring of construction projects through a game-like hybrid application of BIM and machine learning	Rahimian, Seyedzadeh, Oliver, Rodriguez, Dawood	Automation in Construction, Volume 110, 2020	93	Cluster 7
Real-time monitoring of construction quality for gravel piles based on Internet of Things	Real-time monitoring of construction quality	Automation in Construction, Volume 116, 2020	110	Cluster 2

	for gravel piles based on Internet of Things			
The Proliferation of ICT and Digital Technology Systems and their Influence on the Dynamic Capabilities of Construction Firms	Redwood, Thelning, Elmualim, Pullen	Procedia Engineering, Volume 180, 2017, pages 804-811	135	Cluster 1
Analysis of the Situation in Montenegrin Civil Engineering Sector from the Point of Application of National Regulations and the EU Technical Standards in Construction	Rutešić, Ćetković, Žarković, Knežević, Vatin,	Procedia Engineering, Volume 117, 2015, Pages 900-910	26	Cluster 12
Building Information Modelling, Artificial Intelligence and Construction Tech	Sacks, Girolami, Brilakis	Automation in Construction, Volume 114, 2020	137	Cluster 7
3D Printing of Buildings: Construction of the Sustainable Houses of the Future by BIM	Sakin, Kiroglu	Energy Procedia, Volume 134, 2017, Pages 702-711	138	Cluster 3
Chapter 1. 3D Concrete Printing for Construction Applications	Sanjayan, Nematollahi	Editor(s): Jay G. Sanjayan, Ali Nazari, Behzad Nematollahi, 3D Concrete Printing Technology, Butterworth-Heinemann,	88	Cluster 3
Implementation of Mobile Devices on Jobsites in the Construction Industry	Sattineni, Schmidt	Procedia Engineering, Volume 123, 2015, Pages 488-495	29	Cluster 9

Applying rule-based model-checking to construction site layout planning tasks	Schwabe, Teizer, König	Automation in Construction, Volume 97, 2019, Pages 205-219,	0	Cluster 8
Development of new system for detection of bridges construction defects using terrestrial laser remote sensing technology	Sedek, Serwa	The Egyptian Journal of Remote Sensing and Space Science, Volume 19, Issue 2, 2016, Pages 273-283	18	Cluster 5
A Scanner Technology Acceptance Model for Construction Projects	Sepasgozaar, Shirowzhan, Wang	Procedia Engineering, Volume 180, 2017, Pages 1237-1246	49	Cluster 5
Coordinated adjustment and optimization of setting time, flowability, and mechanical strength for construction 3D printing material derived from solid waste	Shahzad, Wang, Wang, Wan, Li, Ren, Mao	Construction and Building Materials, Volume 259, 2020	102	Cluster 0
Data Integration and its Application in the Sponge City Construction of CHINA	Shao, Zhang, Liu, Yang, Chen, Yang, Huang	Procedia Engineering, Volume 154, 2016, Pages 779-786	35	Cluster 12
Architectural education in the digital age: Computer applications: Between academia and practice	Soliman, Taha, El Sayad	Alexandria Engineering Journal, Volume 58, Issue 2, 2019, Pages 809-818	17	Cluster 1

Implementation of Scrum in the Construction Industry	Streule, Miserini, Bartlomé, Klippel, García de Soto,	Procedia Engineering, Volume 164, 2016, Pages 269-276	38	Cluster 12
Analysis of On-site Construction Processes for Effective External Thermal Insulation Composite System (ETICS) Installation	Sulakatko, Lill, Liisma	Procedia Economics and Finance, Volume 21, 2015, Pages 297-305,	107	Cluster 12
IT-based control and assessment of partnering relations in construction projects	Szewczyk, Radziszewska-Zielina	Automation in Construction, Volume 116, 2020	96	Cluster 6
Design automation of control panels for automated modular construction machines	Tamayo, Khan, Qureshi, Al-Hussein	Procedia CIRP, Volume 70, 2018, Pages 404-409	71	Cluster 13
The Changes in the Use of IT on Building Product Information in the Turkish Construction Industry	Tas, Cakmak	Procedia - Social and Behavioral Sciences, Volume 181, 2015, Pages 148-157	21	Cluster 8
Designing a unique Digital Twin for linear infrastructures lifecycle management	Tchana, Ducellier, Remy	Procedia CIRP, Volume 84, 2019, Pages 545-549.	73	Cluster 14
Construction resource efficiency improvement by Long Range Wide Area Network tracking and monitoring	Teizer, Neve, Li, Wandahl, König, Ochner, König, Lerche	Automation in Construction, Volume 116, 2020	97	Cluster 2
Direct digital construction: Technology-based operations management practice for continuous improvement of construction industry performance	Tetik, Peltokorpi, Seppänen, Holmström	Automation in Construction, Volume 107, 2019	12	Cluster 13

Visual Management in Mid-sized Construction Design Projects	Tjell, Bosch-Sijtsema,	Procedia Economics and Finance, Volume 21, 2015, Pages 193-200,	66	Cluster 12
BIM Level of Detail for Construction Site Design	Trani, Cassano, Todaro, Bossi	Procedia Engineering, Volume 123, 2015, Pages 581-589	30	Cluster 13
Challenges of Implementing New Technologies in the World of BIM – Case Study from Construction Engineering Industry in Finland	Tulenheimo	Procedia Economics and Finance, Volume 21, 2015, Pages 469-477.	68	Cluster 1
Potentials of Blockchain Technology for Construction Management	Turk, Klinc	Procedia Engineering, Volume 196, 2017, Pages 638-645	54	Cluster 10
Key Technologies in the Design and Construction of 300m Ultra-High Arch Dams	Wang	Engineering, Volume 2, Issue 3, 2016, Pages 350-359	61	Cluster 11
Identifying potential opportunities of building information modeling for construction and demolition waste management and minimization	Won, Cheng	Automation in Construction, Volume 79, 2017, Pages 3-18	140	Cluster 1
Digital construction_ From point solutions to IoT ecosystem	Woodhead, Stephenson, Morrey	Automation in Construction, Volume 93, 2018, Pages 35-46	141	Cluster 14
Voxel design of additively manufactured digital material with customized thermomechanical properties	Yuan, Wang, Rosen, Ge	Materials & Design, 2020	132	Cluster 3

TWINKLE: A digital-twin-building kernel for real-time computer-aided engineering	Zambrano, Rodríguez-Barrachina, Calvo, Izquierdo,	SoftwareX, Volume 11, 2020.	83	Cluster 5
Key technologies and risk management of deep tunnel construction at Jinping II hydropower station	Zhang, Liu, Chu	Journal of Rock Mechanics and Geotechnical Engineering, Volume 8, Issue 4, 2016, Pages 499-512	121	Cluster 11
BIM-enabled Modular and Industrialized Construction in China	Zhang, Long, Lv, Xiang	Volume 145, 2016, Pages 1456-1461	32	Cluster 13
Real-time resource tracking for analyzing value-adding time in construction	Zhao, Seppänen, Peltokorpi, Badihi, Olivieri	Automation in Construction, Volume 104, 2019, Pages 52-65	11	Cluster 8
Mapping computer vision research in construction: Developments, knowledge gaps and implications for research	Zhong, Wu, Ding, Love, Li, Luo, Jiao	Automation in Construction, Volume 107, 2019	142	Cluster 9
Evaluation of urban underground space resources using digitalization technologies	Zhu, Huang, Li, Zhang, Liu	Underground Space, Volume 1, Issue 2, 016, Pages 124-136	85	Cluster 5
Development of 3D printable engineered cementitious composites with ultra-high tensile ductility for digital construction	Zhu, Pan, Nematollahi, Zhou, Zhang, Sanjayan	Materials & Design,Volume 181, 2019	5	Cluster 0

Interoperability in Construction – Mission Impossible?	Žiga Turk	Developments in the Built Environment, 2020	87	Cluster 12

List of references

Academic literature and books

T. Alam, *A Reliable Communication Framework and Its Use in Internet of Things (IoT),* International Journal of Scientific Research in Computer Science, Engineering and Information Technology, May 2018.

Bertelsen, Sven, *Construction as a complex system,* Proceedings for the 11th annual conference of the International Group for Lean Construction, 2003

Cachola, Isabel, Lo, Kyle, COhan, Arman, Weld, Daniel S., "TLDR: Extreme Summarization of Scientific Documents ", Association for Computational Linguistics (2020): 4766-4777.

Cukier, Kenneth, and Viktor Mayer-Schoenberger. *The rise of big data: How it's changing the way we think about the world*, Foreign Aff. 92 (2013): 28.

Devlin, Jacob, Chang, Ming-Wei, Lee, Kenton, Toutanova, Kristina, *BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding*, Proceedings of the 2019 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, Vol. 1 (2019), 4171-4186.

Néstor Duch-Brown, Fiammetta Rossetti, *Digital platforms across the European regional energy markets*, Energy Policy, Volume 144, 2020.

Feagin, Joe R., Anthony M. Orum, and Gideon Sjoberg, eds. *A case for the case study*. UNC Press Books, 1991.

Grootendorst, Maarten, "Topic Modeling with BERT" (2020). https://www.maartengrootendorst.com/blog/bertopic/

Haskel, Jonathan, and Stian Westlake, *Capitalism without capital: the rise of intangible economy*. Oxford, 2018.

Helbing, Dirk, *Thinking ahead-essays on big data, digital revolution, and participatory market society*. Vol. 10. Cham: Springer, 2015.

Helbing, Dirk, Caron, and Helbing. *Towards digital enlightenment*. Springer International Publishing, 2019.

Charles I. Jones and Christopher Tonetti, *Nonrivalry and the Economics of Data,* American Economic Review 2020, 110(9): 2819–2858

Marin Jovanovic, David Sjödin, Vinit Parida, *Co-evolution of platform architecture, platform services, and platform governance: Expanding the platform value of industrial digital platforms*, Technovation, 2021.

Juenze, Teizer, Mueller, Bickle, *SmartSite: Intelligent and autonomous environments, machinery, and processes to realize smart road construction projects,* Automation in Construction, Volume 71, Part 1, November 2016, pages 21-44.

Lewis, S. Kraus, M. Breier, and S. Dasí-Rodríguez. *"The art of crafting a systematic literature review in entrepreneurship research"* International Entrepreneurship and Management Journal 16.3 (2020): 1023-1042.

S. Kumar, Sree, et al. *The Data Economy: Implications from Singapore*, Routledge, 2018, page 7

Manor, Ilan. *The digitalization of public diplomacy*, Cham: Palgrave Macmillan, 2019.

Marr, Bernard. *Big Data: Using SMART big data, analytics and metrics to make better decisions and improve performance*. John Wiley & Sons, 2015.

Marr, Bernard. *Big Data: Using SMART big data, analytics and metrics to make better decisions and improve performance*. John Wiley & Sons, 2015.

Marr, Bernard. *Big data in practice: how 45 successful companies used big data analytics to deliver extraordinary results*. John Wiley & Sons, 2016.

M Marr, Bernard. *Data strategy: How to profit from a world of big data, analytics and the internet of things*. Kogan Page Publishers, 2017.

Mayer-Schönberger, Viktor, and Thomas Ramge. *Reinventing capitalism in the age of big data*. Basic Books, 2018.

Mike et al., *BART: Denoising Sequence-to-Sequence Pre-training for Natural Language Generation, Translation, and Comprehension*, Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics (2020): 7871-7880.

Mastrogiacomo, Barravecchia, Franceschini, *Definition of a conceptual scale of servitization: Proposal and preliminary results,* CIRP Journal of Manufacturing Science and Technology 29 (Part B): 141-156, May 2020.

McCormick, Chris, *BERT Word Embeddings Tutorial* https://mccormickml.com/2019/05/14/BERT-word-embeddings-tutorial/

D. Mourtzis, J. Angelopoulos, N. Panopoulos, *A survey of digital B2B platforms and marketplaces for purchasing industrial product service systems: A conceptual framework*, Procedia CIRP, Volume 97.

Raffel, Colin et al., "Exploring the Limits of Transfer Learning with a Unified Text-to-Text Transformer", Journal of Machine Learning Research 21 (2020): 1-67.

Schwab, Klaus. *The fourth industrial revolution*, Currency, 2017.

Shantanu Mullick, Néomie Raassens, Hans Haans, Edwin J. Nijssen, *Reducing food waste through digital platforms: A quantification of cross-side network effects*, Industrial Marketing Management, 2020.

Sia, Suzanna, Dalmia, Ayush and Mielke, Sabrina J. "Tired of Topic Models? Clusters of Pretrained Word Embeddings Make for Fast and Good Topics too!", Proceedings of the 2020 Conference on Empirical Methods in Natural Language Processing (EMNLP) (2020): 1728-1736.

Stake, R. E., *Multiple case study analysis*. Guilford press, 2013.

Vrijhoef, R. and Michael K. Tong Understanding Construction as a Complex and Dynamic System: An Adaptive Network Approach", 2004.

Aneesh Zutshi, Antonio Grilo, Tahereh Nodehi, *The Value Proposition of Blockchain Technologies and its impact on Digital Platforms*, Computers & Industrial Engineering, 2021.

Other reports

The Data Economy Report, Digital Reality, 2018, see: https://www.digitalrealty.com/data-economy

Key figures 2019, *Construction activity in Europe*, edition 2020, FIEC.

Reinventing construction – A route to higher productivity, McKinsey, February 2017.

Economic regulator: The UK Construction Industry: https://www.mcmdev.com/stories/economic-regulator

Digitalising the construction sector – Unleashing the potential of data with a value chain approach, CECE, January 2019.

6 ways the construction industry can build for the future, Boston Consulting Group, World Economic Forum, 2018.

Daron Acemoglu, *Antitrust Alone Won't Fix the Innovation Problem,* Project Syndicate, 30 October 2020.

T. Baines, *Towards a Common Definition of Servitization,* 2016, Aston Business School.

Castagnino, Rothballer, Renz, and Filitz, *The Transformative Power of Building Information Modeling*, March 2018, Boston Consulting Group.

Olaf Cramme*, Is Europe offering a Third Way in technology regulation?,* 19 February 2019.

World Economic Forum, *Shaping the future of construction – A breakthrough in mindset and technology*, May 2016, page 47.

Klaus Schwab, *The Fourth Industrial Revolution: what it means, how to respond***,** 14 January 2016.

Flipping the Odds of Digital Transformation Success, Forth, Reichert, de Laubier, Chakraborty, 29 October 2019

McKinsey, *10 imperatives for Europe in the age of AI and automation* (2017).

M. Schinina, *Rule of law as integral part of the next MFF: to what extent and why?*, January 2020.

McKinsey, *Imagining construction's digital future,* June 2018.

McKinsey, *Jobs lost, jobs gained: What the future of jobs will mean for jobs, skills and wages*, November 2017.

Accenture, *Why Artificial Intelligence is the Future of Growth*, Purdy and Daugherty, 2016.

EU official documents

COM(2021) 118 final, *2030 Digital Compass: the European way for the Digital Decade*, 2021.

COM(2017) 9 final, *Building a European Data Economy,* 2017.

COM(2020) 66 final, *A European strategy for data,* 2020.

COM(2020) 65, *White paper on artificial intelligence, 2020.*

COM(2020) 67 final, *Shaping Europe's digital future*, 2020, page 3.

COM(2020) 67 final, *Proposal for a Regulation of the European Parliament and of the Council on European data governance (Data Governance Act)*, 2020.

COM(2020) 456 final, *Europe's moment: Repair and Prepare for the Next Generation*, 2020.

COM(2020) 622 final, *A Renovation Wave for Europe – greening our buildings, creating jobs, improving lives*, 2020.

COM(2020) 842 final*, Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on contestable and fair markets in the digital sector (Digital Markets Act).*

COM(2020) 575 final, *Annual Sustainable Growth Strategy 2021*, 2020.

COM(2014)14 final, *For a European Industrial Renaissance*

COM(2012) 433, *Strategy for the sustainable competitiveness of the construction sector and its enterprises*, 2012.

SWD(2020) 295 final, *Impact Assessment Report accompanying the Proposal for a Regulation of the European Parliament and of the Council on European data governance*, 2020, pages 17-18.

SWD(2018) 125 final, *Guidance on sharing private sector data in the European data economy*.

SEC(2020) 437/2 REGULATORY SCRUTINY BOARD OPINION Proposal for a Regulation of the European Parliament and of the Council on contestable and fair markets in the digital sector (Digital Markets Act).

A New European Bauhaus: op-ed article by Ursula von der Leyen, President of the European Commission, October 2020.

Renovation Wave: doubling the renovation rate to cut emissions, boost recovery and reduce energy poverty, Press release, 14 October 2020

JRC Digital Economy Working Paper 2018-09, *The impact of data access regimes on artificial intelligence and machine learning*, Bertin Martens, page 11.

Buildings and construction, URL: https://ec.europa.eu/growth/industry/sustainability/built-environment_en

Digital Transformation in Transport, Construction, Energy, Government and Public Administration, JRC Science for Policy Report, 2019, page 99.

DESI Key indicators, URL: https://digital-agenda-data.eu/

Handbook for the introduction of Building Information Modelling by the European Public Sector, EU BIM Task Group, page 4.

JRC Technical Reports, *Building Information Modelling (BIM) standardization*, 2017

A Blueprint for Sectoral Cooperation on Skills (Wave II), 2018.

SOTEU 2020, President von der Leyen's speech, 16 September 2020.

A Europe that strives for more, *My agenda for Europe by candidate for President of the European Commission*, Ursula von der Leyen.

Europe fit for the Digital Age: Commission proposes new rules for digital platforms, 15 December 2020

A definition of the AI, HLGE, 8 April 2019

European Economic Forecast (Autumn 2020), European Economy – Institutional Paper, 136 (November 2020).

Special meeting of the European Council (17, 18, 19, 20 and 21 July 2020) – Conclusions.

Study on Monitoring of sectoral employment, final report, contract VC/2010/0064.

ECSO, *Digitalisation in the construction sector*, Draft Analytical Report, April 2021.

What do Europeans do at work? A task-based analysis: European Jobs Monitor 2016. Publications Office of the European Union. Luxembourg.