ARTIFICIAL INTELLIGENCE - RESEARCH AND INNOVATON NEEDS
MANUFACTURING, ENERGY INTENSIVE INDUSTRIES, BIO-BASED INDUSTRIES AND CONSTRUCTION

FOCUS ON THE CONSTRUCTION AND BUILT ENVIRONMENT SECTOR

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*BY **ECTP** – THE EUROPEAN CONSTRUCTION TECHNOLOGY PLATFORM – AND THE ENERGY-EFFICIENT BUILDING / **EeB cPPP***

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Background

In June 2018, the Commission presented its proposal for Horizon Europe. Its second pillar "Global Challenges and Industrial Competitiveness" builds on the societal challenges and industrial technologies of Horizon 2020 and aims to foster competitiveness, to deliver on the Unions strategic priorities and to contribute to tackling global challenges. If the European Parliament and the Council will find a common understanding on the content (but not on the budget allocation) in the coming weeks, consultations on strategic programming of the investment priorities under the second pillar 2 of Horizon Europe could start before summer 2019.

In December 2018, the Commission presented its coordinated plan on Artificial Intelligence. Amongst its priorities, it highlighted the need to develop a future common strategic research agenda on AI. In addition, the creation of a common European Data Space is planned for the benefit of European innovators and businesses. The coordinated plan is envisaged to be updated regularly.

Objective

The objective is to identify the research and innovation needs related to AI in relation to

a) the strategic planning for Horizon Europe,
b) the future common strategic research agenda and the common European data space announced under the December AI Communication.

The resulting papers will be presented and discussed at Finnish presidency conferences.

Specificities of the construction sector

The construction sector is of strategic importance for many countries across the world. It delivers, maintains and dismantles or upgrades the buildings and infrastructure needed by the rest of the economy and society. It represents about 9% of gross domestic product (GDP) in the European Union and provides 18 million direct jobs. The construction value chain includes a wide range of economic activities, going from the extraction of raw materials, the manufacturing and distribution of construction products up to the design, construction, management and control of construction works, their operation, maintenance, renovation and demolition, as well as the recycling of construction and demolition waste[1]. Construction sector has a global impact of the world around $10 trillion[2]. European construction companies are world leaders in this sector (six of the top ten construction companies are European[3]).

From a general point of view, the construction sector value chain is quite similar to the value chain of any other industrial process: specification, design, manufacturing, delivery, operation and maintenance and end of life. However, construction industry has several specificities that implies new challenges that are analyzed hereafter:

- **Each project is different**. Industrial processes usually are oriented to serial production, products customization being a reconfiguration of predefined components. Although construction industry is following that trend, it will always be a “project oriented” industry instead of a “product oriented” one. Nowadays buildings and infrastructures already integrate many on-the-shelves products (doors, windows, stairs, beams…) but even in these cases the prefabricated products have to be adapted to the requirements of each construction project, which depend on multiple aspects: climatic conditions, urban restrictions, geotechnical aspects, architectural value, end-user requirements, etc.
- **Dynamic working environment**. The vast majority of the industrial processes follow a “product mobility” approach, the workshops are static, and the product is moved from one workshop to the next one until finishing the production process. The construction process follows a “team mobility” approach, the product (the building or the infrastructure) cannot be moved, but the teams with their equipment have to move from one building site to another. Working environment permanently changes, both during the life of the project (i.e. to each floor in a building or along a road or a railway), and from project to project. Consequently, the systems have to be mobile, more configurable to permanently adapt to the new working environment, robust, lighter…
- **Uncontrollable working environment.** Commonly, industrial facilities are a collection of stable workshops where all the environment is predefined and controlled (access to the workshop, layout of the equipment and work places, warehouses, weather conditions…). Construction sites are very large and dynamic open spaces, much more difficult to control and exposed to many unexpected events, as changes in weather conditions or accessibility, that oblige to permanently reschedule the work plan and coordinate many *decoupled* work teams (teams in the construction site with teams in the materials and machinery suppliers’ sites; contractors and sub-contractor teams…).

[1] “The European construction sector. A global partner - 2016 edition”. European Commission.
[2] Reinventing construction: A route to higher productivity - McKinsey&Company; Febreuary 2017
[3] “Top 10 Biggest Construction Companies in the World and What Makes Them Great”, eSUB Construction Software.

- **Highly fragmented value chain** *(95% of SMEs with fewer than 20 employees and 93% with fewer than 10[4])*. Building and infrastructure projects are very large and complex projects. They require thousands of hours of labour force, deploying thousands of tons of construction materials, assembling of thousands of components… These imply that a large chain of contractors and subcontractors has to be mobilized. But due to the need of proximity to the construction site, this chain has to be redefined for each project. Consequently, the value chain is very fragmented and different from project to project. So, any innovative process requires fast learning curve, extremely short ROI (Return of Investment) periods and a very high standardization level to assure compatibility and interoperability among the processes of multiple stakeholders, etc..
- **Low digitalization.** As a consequence of the combination of all the above-mentioned factors, the construction sector is the economic sector with the lower digital intensity index in the EU[5]. Indeed, digitalization correlates very often with the size of the company. Although many of the enterprises in the sector have already initiated their digitalization, in many cases they are still in the 1st level of the Digital Transformation (*1. Business as usual*)[6]. ICT tools have been adopted to develop specific and isolated tasks, but these tools have no impact in the processes of the organization. For example, the progress monitoring of the project is based on data (sometimes digital data, as digital pictures, excel sheets…) that are manually collected by the construction site management team. However, the high fragmentation of the value chain, the geographical dispersion of the work teams, the large dimension of the construction sites and their permanent evolution creates a very challenging environment for the deployment of digital technologies, but also with the promises of a huge potential to increase the productivity of the sector and quality of its products. This is even more acute when considering that 92% of the sector are dealing with small scale, low-tech new builds or renovation market mostly for the private residential sector or as subcontractors in small-medium size operations. Whereas they represent 80% of the output of the whole sector, these SMEs are currently dramatically lagging behind on the digital transformation, because they are simply striving to survive using their traditional, low tech skills in a very competitive context. We could even argue here that they are at “level 0” of the Digital Transformation.
- **Very long product lifetime.** Compared to product-oriented sectors like applications or even vehicles, infrastructures (roads, bridges, buildings) have a very long lifetime, usually over several decades. The digital sector is characterized by much shorter time frames and much faster development cycles. Reconciling and aligning very different industrial dynamics is a challenge in terms of interoperability and sustainability of infrastructure operating systems.
- **In the way toward the industrialization.** Although each construction project is different from the other, the sector is evolving toward the standardization and the transformation of the work sites from craft workshops to assembly plants. Off-site construction although not being a new modus operandi for the industry (concrete prefabrication was pervasive in the Post War reconstruction in Europe), is coming back to the forefront thanks to the emergence of new technologies, and especially Building Information Modelling, automation and improved, digitalized quality checks. These evolution in the business model creates a very favorable context to take advantage of the

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[4] “FIEC Annual Report 2018”

[5] Digital Transformation Scoreboard 2018 - EU businesses go digital: Opportunities, outcomes and uptake. European Commission.

[6] “The Six Stages of Digital Transformation Maturity”. Custom research by Altimeter Group on behalf of Cognizant

synergies between industrialization and digitalization to accelerate the transformation of the construction sector in the top 3P (Professional, Productive, Progressive) sector.

The "Communication Artificial Intelligence for Europe", issued by the European Commission in April 2018[7], defines Artificial intelligence (AI) as *"systems that display intelligent behaviour by analysing their environment and taking actions – with some degree of autonomy – to achieve specific goals"*. Construction sector is extremely dynamic in many aspects: working environments, building components, value chain, etc. In the past, this has been a constraint that has delayed its digitalization. However, the capacity of AI systems to cope with dynamic environments can be the catalyzer that the definitely push its digitalization.

[7] Artificial Intelligence for Europe. COM(2018) 237 final

1. State of play of using AI

The current applications of AI in the sector, and its forms, are embedded with its digital transformation strategies and need to be seen in two dimensions: The design, construction and maintenance of Buildings and Infrastructures, in one dimension and the living environment as "host" of its inhabitant's life processes and interactions in the other dimension. Considering these contexts and all life-cycle and its complexity, all the AI forms are relevant at some phase or process. Machine learning and AI related robots are potentially impactful for the Design stage and for the automation of construction process. The 1st applications emerged recently in the market and are still in early stages of development. Neural networks techniques can bring value to Buildings Energy management systems and its interconnectivity with district/city energy management systems. Due to the above-mentioned sector specificities, in the short-term the estimated AI penetration in the sector is expected to be low even if the needs, potential and willingness are present. However, in the mid to long term, a fast turn is expected with the different sectors breaking down barriers and cross-sectoral AI applications being developed[8]. A momentum is already created in Europe with several applications in advanced stage of research or already under trial and implementation.

As in other application areas, the impact of the different AI forms will depend on the available data quantity, quality and reliability. The Data capture, storage and sharing are key issues and it is one of the hardest to tackle (from a business perspective). Currently data are very disaggregated, and data ownership can create silos that result in not being able to perform a suitable playground to perform meaningful analysis. In the short term this context is likely to give an advantage to the largest companies where the project history is larger. EU level initiatives, as well as National/Regional and holistic/integrated projects with different stakeholders participating and sharing data, could prove the benefit of creating a common data environment. Data platforms hosting (structured) information throughout the building's and infrastructure's lifecycle are key in this context. The integration of these information with sensing applications, e.g. neural networks, image analysis, LIDAR technology (producing point clouds) and other technologies into these platforms will allow for the creation of a "digital twin" of a project improving its monitoring and enhancing decision making processes. In most countries, in more or less advanced stages, BIMs (Building information models) are embedded in the industry processes and become therefore central to advance and integrate AI technologies as well as to feed information to these AI applications. Data platforms should not focus only on the "components" (buildings and infrastructures), they have to address also their context (urban and regional data models) and the aggregation of data from multiple "components" in order to tackle the management of distributed assets and learn from the performances of the existing building stock and users' behaviors.

There are several practical examples of AI applications which are emerging for different construction processes. In the future, these today's disconnected applications will be converging into an integrated and open system for whole lifecycle management. These will allow the emerging of Digital Twins as common platforms included in a business ecosystem with cross-vectoral approach. Current examples for AI applications in various construction processes are indicated in the following paragraphs.

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[8] Artificial intelligence: Construction technology's next frontier. McKinsey&Company; April 2018

1.1. Planning and Design

AI-based machine learning applications, and further analytics and prediction, together with Big data techniques, are very promising to support decision-making on planning as well as design processes by shortening the processing time while enhancing the expertise and experience of the planners or designers[9] [10]. Promising applications are emerging in all stages of the construction process, e.g. project management and delivery, performance, evaluation and risk mitigation, quality-checks and billings[11]. Current research develops solutions, such as integrators and BIM Bots equipped with machine learning and holistic algorithms[12, 13]. Still, the construction sector has to overcome the lack of interoperability of many applications with the risk of losing the full impact and benefits of these technologies.

Intelligent Communities Lifecycle (ICL)
The ICL is based on one Interconnected Platform creating dynamic 3D models that reflect real life performance[14]. It uses a hybrid of simulation coupled with AI to create initial models for planning and decision support, that can then also be used for operational management of buildings or groups of buildings. Where there is not enough data available, simulation is used to generate the model based on available physics information, e.g. type of building, number of floors, use case etc. Then as data is collected over time, the real data replaces the simulated data and it moves towards the AI, data driven model. The shared central database and interconnected tools allow to easily share data and analysis results across the platform.

In initial planning stages, including city planning and planning processes, new applications have emerged. These utilize the open data published by municipalities as the basis for training Machine Learning models[15]. In the design phase, AI applications for handling user feedback on the design process in combination with imaging technologies (VR, AR) are emerging. Along with these, there are applications to simulate scenarios (including Energy Efficiency scenarios), optimize design/operation, and support graphic and structural design[16, 17].

Sweco automating structural design process with machine learning
Sweco is an engineering company which plans and designs buildings, districts and infrastructure. In a research project, now under implementation, the company historical database of tens of thousands of building information models, is used as a reference or training material for machine learning. This supports the designer's decision-making and allows for the automation of certain design processes. Currently the testing and implementation focus on automatically designing the

[9] AI&Architecture. https://towardsdatascience.com/ai-architecture-f9d78c6958e0
[10] http://www.iesve.com/icl
[11] Self-inspection tools and quality checks on a Virtual Construction Management Platform (BUILT2SPEC) http://built2spec-project.eu/
[12] BIM Digital twin Platform (SPHERE) https://sphere-project.eu/technology/
[13] Data-driven Design (BIM4REN) https://bim4ren.eu/#technologies
[14] https://www.iesve.com/icl
[15] http://www.kiradigi.fi/en/experiments/ongoing-projects/machine-learning-algorithms-in-the-construction-sector.html
[16] https://www.sweco.fi/en/news/news-archive/news-2017/sweco-is-looking-for-artificial-intelligence-solutions-in-the-kira-digi-experimental-project-of-the-ministry-of-the-environment/
[17] MaRS Generative Design https://www.world-architects.com/en/architecture-news/insight/the-promise-of-generative-design

joints for new models. It is intended to extend the current implementation to cover other processes. Testing showed that the machine designed 77% of the connections successfully without human intervention. This automation helps Sweco to reduce the time of designing the connections significantly. In order to collect faster benefits, Sweco has decided to start the application development with a specific structure, which is frequent with the company operational market (sandwich panels).

1.2. Construction process

In project delivery, AI-based applications have emerged in the market targeting benefits on reducing costs, time for project delivery and managing risks. Project schedule optimizers consider millions of alternatives and management of everyday risks during project execution is done based on prediction and analysis[18, 19]. Collection of video data and other imaging techniques, as well as sensor data, is currently used to monitor the construction sites to track unsafe worker behaviour as well as inefficiencies related to equipment and material use[20, 21]. Processing and aggregation of this data with image-analysis algorithms or neural networks to compare the actual situation against the design/plan can help detecting the likelihood of events, decreasing accidents on site, and optimizing logistics[22]. In addition, the same applications can be used for training and education.

More specific applications come from the supply chain with examples of research on how AI can be used to support transport, quality assurance and on-site logistic management of materials and components. In a recent research project[23], the concrete industry tested an AI-based construction assistant to collect data across the entire concrete construction process, from design models and databases, to open data sources, and data from IoT sensors. It used weather and traffic data to determine the behavior of ready-mix concrete during transport. It is expected that AI algorithms would control the whole process and product quality and prompt users to make the right decisions throughout the process. This research project also included tests on concrete quantity estimation, mold heating during the winter, logistics optimization, raw material quality control, and safety on the construction site as well as the development of digital measurement methods and sensor technologies for concrete quality measurement. A start-up has been created from this research and it is testing different applications in the relevant domain[24].

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[18] https://www.autodesk.com/bim-360/construction-management-software/construction-data-analytics-reporting/machine-learning-construction-management/

[19] https://alicetechnologies.com/

[20] https://leica-geosystems.com/case-studies/building/long-term-monitoring-of-a-construction-site

[21] https://www.sigicom.com/products/

[22] https://www.indus.ai/solutions/construction-intelligence/

[23] http://www.kiradigi.fi/en/experiments/ongoing-projects/hands-on-tests-of-digital-tools-in-the-concrete-construction-industry.html

[24] https://thehub.fi/jobs/company/caidio

Safety Assistance Manager

A Hackathon on Digital Construction was launched in 2018 in Brussels in collaboration between the Construction Confederation and the Belgian Building Research Institute[25]. The winning team had developed an AI approach using image analysis to safety on site. The "Safety Assistance Manager" alerting unsafe situations based on video footage indeed won an official award and the team was invited to present their project at the management board of two major contractors in Belgium i.e. Besix and Willemen. Work is now in progress to develop the idea further. Safety issues on site are still a major issue. In Belgium for example, still over 10% of all accidents at work emerge from the construction sector. The hackathon major focus was on Artificial Intelligence and Big Data, Digital experience with 3D Technology, Automated Lean measurement and; Track & Trace and IoT.

The integration of AI techniques with robotics and automation technologies is also emerging although currently remains within the larger construction projects. The vast majority of small and medium construction companies, heavily dependent on manual work, are still difficult to benefit from this innovation in the near future. Similar with other industries, the application of robotics in extreme conditions and modular assembly (on-site) would improve the operations speed and performance as well as of quality control[26]. Robotics can also be applied for processes, such as 3D printing, inspection, demolition, and excavations. While robotic and automation technologies have been tested, their integration with AI is still in an early stage, and many challenges regarding regulations, workers skills, and complexity of the construction sites are still unresolved. Furthermore, while technology and new AI applications might be quick to achieve adequate technology readiness levels (specially the most unambiguous and sector-transversal ones), challenges will still remain in the medium term on information management and liabilities due to the complexity supplier and subcontractor networks involved in the building and infrastructure projects. The development of Smart Contracts and faster (nearly real-time) integration of other technologies, such as Blockchain, may be able to overcome these challenges.

1.3. Operation and maintenance

In the operational and maintenance phase of buildings and building stock, AI will most likely have a faster penetration and growth in short term. Although it is still a complex and changing environment, this phase is characterized by repetitive and more stable operational conditions involving fewer stakeholders. Integrated Building Management Systems or BMS (including local energy management systems and its integration with the overall energy system) and portfolio management are more advanced in terms of digital transformation as much data is available for the development of predictive and controlling algorithms integrated with AI applications. Much data captured by sensors can be used to train AI algorithms and to create digital twins.

[25] https://www.digitalconstruction.be/
[26] https://www.doxel.ai/

Moreover, the BMS is developing towards a seamless integration with the building occupants' daily living patterns. BMS is also extending to interact with district and urban systems. Within this context, there is a tendency for the "good life" domain applications for building maintenance and operation and for digital transformation of the energy systems. Challenges in this area are predominantly due to data ownership and citizens' privacy issues. There are more and more examples of currently AI applications for forecast; predictive and proactive maintenance; self-healing based on machine learning algorithms; multi-energy and flexible grids; indoor comfort and user-centric operational management; and portfolio management. A selection of these examples:

- A number of applications to optimize energy efficiency by reducing energy consumptions and costs as well as to support predictive maintenance. These applications combine sensor technology, Internet of Things (IoT), AI with machine learning, and automated demand response services on service platforms[27, 28, 29]. Such applications can scale from building to block-of-buildings, thus enabling Positive Energy Blocks.
- Prediction of failures and energy consumption of equipment. AI is feed by real-time sensor data of building's energy use as well as information about weather forecast and building occupancy[30].
- AI-based building portfolio management services for real estate owners are emerging for forecasting economic values, profitability, energy consumption and CO_2 emissions. These services combine automatic valuation systems and digitized technical surveys. Their algorithms extract property's technical risks from the market values[31].

Leanheat: Optimizing energy efficiency of buildings with AI

Leanheat offers a service platform targeting improvement of buildings' energy efficiency and predictive maintenance with Artificial Intelligence and Sensor Technology. The system works with a cloud-based Artificial Intelligence and Machine Learning that can understand and predict the heat demands and behaviors of buildings by means of Internet of Things sensor networks and heat controllers in individual apartments. The collected data is used to optimize building heating imbalances and to dynamically adjust the building heating systems. Leanheat is designed for centrally-heated residential buildings, and it aims at smart and cost-efficient district heating.

The customers of Leanheat are residential property owners. The solution is suitable for all kind of properties, but it brings the biggest impact at retrofitting of older buildings. The service model provides heat energy optimization based on a service-level-agreement where indoor climate targets are defined. Leanheat has a fast growth path in Finland. At the end of 2018, installations have been made in more than 100,000 apartments. Globally, trials are ongoing in China, Germany, Denmark, Sweden, and Norway. The company adopts an open approach to new hardware and services, and it operates under an open business ecosystem for synergies or partnerships. Leanheat shows that Artificial intelligence and predictive analysis allow not only for smart property management, but also for new business models.

[27] https://leanheat.com/for-building-owners/
[28] https://buildingiq.com/products/predictive-control/
[29] https://new.siemens.com/global/en/products/buildings/automation/desigo/building-management
[30] https://verdigris.co/#analytics
[31] https://skenariolabs.com/

1.4. EC funded R&D

Table 1 shows a set of current ongoing EC funded R&D projects, which are currently researching, in some form, AI applications within the built environment domain. Two project examples are further presented below. The experience from the implementation of these projects will offer new insights of the challenges and opportunities for AI applications in the sector.

Table 1:

Call	Acronym – Title	Coordinator
H2020-NMBP-EEB-2018 10.2018-09.2022	**BIM4REN** Building Information Modelling based tools & technologies for fast and efficient RENovation of residential buildings - www.bim4ren.eu	NOBATEK/INEF4, FRANCE
H2020-NMBP-EEB-2018 01.2019-09.2022	**BIMERR** BIM-based holistic tools for Energy-driven Renovation of existing Residences https://bimerr.eu/	FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.
H2020-NMBP-EEB-2018 11.2018-10-2022	**BIM-SPEED** Harmonised Building Information Speedway for Energy-Efficient Renovation www.bim-speed.eu	TECHNISCHE UNIVERSITAT BERLIN
H2020-EeB-2014 01.2015-12-2018	**BUILT2SPEC** Built to Specifications: Self-Inspection, 3D Modelling, Management and Quality-Check Tools for the 21st Century Construction Worksite www.built2spec-project.eu	NOBATEK/INEF4, FRANCE
H2020-NMBP-EEB-2018 01.2019-02-2022	**ENCORE** ENergy aware BIM Cloud Platform in a COst-effective Building REnovation Context www.encorebim.eu/	INSTITUT FÜR ANGEWANDTE SYSTEMTECHNIK BREMEN GMBH
H2020-EeB-2015 09.2015-08-2019	**HIT2GAP** Highly Innovative building control Tools Tackling the energy performance GAP http://www.hit2gap.eu/	NOBATEK/INEF4, FRANCE
H2020-EE-2017-PPP 10.2017-09.2020	**HOLISDER** Integrating Real-Intelligence in Energy Management Systems enabling Holistic Demand Response Optimization in Buildings and Districts http://holisder.eu/	FUNDACION TECNALIA RESEARCH & INNOVATION
H2020-EeB-2015 09.2015-02.2019	**OPTEEMAL** Optimised Energy Efficient Design Platform for Refurbishment at District LeveLwww.opteemal-project.eu/	FUNDACION CARTIF
H2020-EeB-2015 01.2016-12.2019	**QUANTUM** Quality management for building performance – Improving energy performance by life cycle quality management www.quantum-project.eu	INSTITUTE FOR BUILDING SERVICES AND ENERGY DESIGN (IGS), TU BRAUNSCHWEIG
H2020-EE-2017-PPP 10.2017-09.2020	**RESPOND** integrated demand REsponse Solution towards energy POsitive NeighbourhooDs www.project-respond.eu	FENIE ENERGIA SA
H2020-NMBP-EEB-2018 11.2018-10.2022	**SPHERE** Service Platform to Host and SharE REsidential data www.sphere-project.eu	IDP INGENIERIA Y ARQUITECTURA IBERIA SL
H2020-EeB-2015 11.2015-10.2018	**TOPAS** Tools for Continuous Building Performance Auditing www.topas-eeb.eu	MOTOROLA SOLUTIONS ISRAEL

BUILT2SPEC[32] project aimed at reducing the gap between a building's designed and as-built energy performance. To do this, the project put a new set of breakthrough technological advances for self-inspection checks and quality assurance measures into the hands of construction professionals. This collection of smart tools helps building stakeholders at all levels in meeting EU energy efficiency targets, new build standards and related policy goals. The set of tools concerns: 3D and Imagery, Building Information Modeling (BIM), Smart Building Components, Energy Efficiency Quality Checks, Indoor Air Quality, Airtightness Test Tools with air-pulse checks, Thermal Imaging and Acoustic.

[32] BUILT2SPEC, www.built2spec-project.eu, (RIA, H2020-EeB-2014)

They are all connected to a Virtual Construction Management Platform (VCMP) supporting the collection and sharing of all project data, from initial design to the delivery. During the project, this platform was integrated into the operations of small and medium-sized enterprise (SME) contractors, large construction firms and end user clients directly within the consortium and work program activities, assuring systematic and scientific performance measures, feedback and powerful exploitation.

SPHERE[33] project aims to provide a BIM-based Digital Twin Platform to optimise a building's energy performance throughout its lifecycle, and to reduce time, costs and the environmental impact of the construction process. The project integrates two planes of research, innovation and improvement: a) A Building-centered Digital Twin Environment, involving not only the design and construction of the Building but including also the manufacturing and the operational phases and; b) The seamless and efficient updating and synchronization of SPHERE's Digital Twin platform based on an Integrated Design and Delivery Solutions (IDDS) framework.

This Digital Twin concept is in fact a distributed but coordinated Database, including geometrical objects information that forms a unique synchronized virtual model of the reality, which can significantly help in decision-making during each phase of the whole building's lifespan (manufacturing, design, construction, maintenance, operation, retrofitting and even demolition). The SPHERE cloud-ICT platform will allow to interact all different stakeholders during any phase of the asset with a building Digital Twin model of information of the building and a scalable set of different software tools, such as energy demand/performance simulation tools, Decision Support and Coaching Systems, BEMs or IoT enabled Predictive Maintenance Algorithms.

[33] SPHERE, www.sphere-project.eu, (IA, H2020-NMBP-EEB-2018)

2. Planned investments amongst your communities

According to the Artificial Intelligence for Europe strategy that was launched by the EC in April, 2018[34], several EU Member States developed, or are developing, AI strategies, roadmap and initiatives, to different level of detail. Public investments have been announced under strategies/initiatives/platforms in the EU Member States (*see table 2 in ANNEX 1*). However, contents on these are usually very broad, general, and if they lack financing support, will be difficult to develop. Moreover, in many cases, authors come from the university or RTOs, and private companies have been left aside: the roadmaps should include the way forward for different key industries, including construction.

Besides the efforts being done by the Public Sector in the preparation of the framework documents and guides, as noted above, the digitalization of the construction sector is widely recognized as a priority by the sector itself, in order to boost its competitiveness. Words like robotics, data science or Artificial Intelligence are on everyone's lips in the construction industry. BIM, which just few years ago was in its inception, it is now used in projects of different size and nearly business as usual in the sector. In the larger companies, AI is one of the areas identified as a priority for digital innovation because of the potential business impact it might bring.

It is commonly accepted that average R&D investment in the construction industry is around 1%, against 3.5-4% from other sectors like automotive or aerospace[35]. This drawback can be turned into an opportunity and the construction industry not only is aware of the situation, but the topic is raising interest and the companies realize that the investment in their digitalization will help them to improve their financial statement in the short and medium term, but it will actually be a need for survival in the long term.

An Ernst & Young survey carried out among executives of Engineering and Construction firms[36] states that only 28% of the respondents have a digital strategy and agenda in place, while 56% are in the process of designing. Despite this recognition, many companies may confuse the deployment of an actual Digital Strategy and the advantage that the Digital Innovation can bring in their companies with the implementation of BIM in a few projects. Nevertheless, 98% of the respondents agree that digital solutions will be critical to the future viability of their company. It is wise to think that companies will tend to keep on the market and survive or grow, and hence, investments to achieve that goal will be projected in the short and medium term.

It is barely impossible, and probably unrealistic, to give a figure of the project investments in AI by the construction sector until 2025. Individual private companies will not give public notice of their investments, since that is part of the business strategy, and gathering a sector figure is also very hard to achieve. However, based on known figures, projected estimates based on well-respected reports and given assumptions, it is possible to at least give some try out to this fact.

[34] Artificial Intelligence for Europe. https://ec.europa.eu/transparency/regdoc/rep/1/2018/EN/COM-2018-237-F1-EN-MAIN-PART-1.PDF

[35] Imagining Construction's digital future – McKinsey&Company; June 2016

[36] How are engineering and construction companies adapting digital to their businesses? – Ernst & Young; 2018

As we said before, construction sector has a global impact of the world around $10 trillion[37]. Construction industry is growing, and it is expected to reach a business figure of $17.5 trillion by 2030[38]. This same report states that digital transformation can bring a real benefit to the business, within 10 years, estimated in cost savings up to $1.2 trillion in the engineering and construction phase for non-residential projects. McKinsey report[39] forecasts in $1.6 trillion (annually) the potential rise for the industry's value added if construction productivity would raise to average level of other industrial sectors.

The digital transformation of the sector will be one of the key drivers to close the productivity gap, and construction companies are "leveraging technologies like artificial intelligence, cloud-based data analytics, and mobile computing to drive efficiency and boost margins"[40]. McKinsey states that construction technology firms have garnered $10 billion investment funding from 2011 to 2017. Other reports like Oliver Wyman's "Digitalization of the Construction Industry: the revolution is underway[41]" increase that figure to $ 19.4 billion in funding since 2010, with half of that investment happening in 2017, and accounting for more 1200 startups as construction related companies.

As we first said, it is nearly impossible to give an exact figure, but it is out of the question the fact that technology startups are looking into the sector, and that investment funds and venture capital companies are backing these startups providing them funds for grow – that is a clear signal that the construction industry is adapting and transforming itself.

As we may reckon, the figures given are already based on well documented and respected reports and yet, they are dispersed and difficult to assess. In any case, it is clear that the digital transformation of the construction sector has come to stay. However, there is no figure that can represent accurately the investment the construction industry will be facing in the next years. If we would like to make a very rough figure assumption, we could consider that over the $7 trillion investment increase in the next few years, the R&D investment will increase from 1 to 2.5%: that would represent an investment of $175 billion.

Looking into some individual technologies for which we may find some estimates, we can see that the use of drones in the construction industry will grow up to €9.7 billion in the period 2016-2020[42], or that 3D Printing use is expected to grow from $0.04 billion in 2016 to $40 billion in 2027[43]. Considering the importance Artificial Intelligence is gaining, it can be assumed that the investment figures in AI in the construction sector will be in the billions scale for the next years, in line with the investments expected in other technologies, like those named before.

Other studies suggest that intelligent building solutions revenue is expected to grow from approximately $15.1billion (2018) to $67.5bn (2027) at a compound annual growth rate (CAGR) of

[37] Reinventing construction: A route to higher productivity - McKinsey&Company; February 2017
[38] Five keys to unlocking digital transformation in Engineering & Construction – Oracle and BCG
[39] Reinventing construction: A route to higher productivity - McKinsey&Company; February 2017
[40] http://fortune.com/2018/10/02/construction-industry-technology/
[41] Digitalization of the Construction Industry: the revolution is underway – Oliver Wyman;2018
[42] Goldman Sachs Research 2016, Technology driving innovation: Drones, https://www.goldmansachs.com/insights/technology-drivinginnovation/drones/
[43] https://www.3dnatives.com/en/3d-printing-construction-240120184/

18.1%[44]; and global revenue for energy efficiency commercial building retrofits is expected to grow from $71.4billion (2016) to $100.8billion (2025)[45].

Besides the private investment, the European Commission recognizes that investment levels for AI in the EU are low, and it has presented a strategy for AI in Europe to boost this investment. The plan expects public and private investment in AI in Europe of at least €20 billion until the end of 2020, and more than €20 billion per year from public and private investments over the following decade. The EU will compliment this figure by investing €1.5 billion by 2020, and €7 billion for the Horizon Europe programme. Breaking down that figure per sector is unrealistic. However, if we would consider an investment range for the construction sector between 1 and 10% of the total investment figure, we would be considering investments ranging between €2 and €20 billion (total cumulative investment) over the next decade, which it is in line with the estimates given above for other technologies like 3D printing or drones.

[44] Navigant Research (2016) Executive Summary: Energy Efficiency Retrofits for Small and Medium Commercial Buildings, Research Report

[45] Navigant Research (2018) Executive Summary: Intelligent Buildings Market Overview Hardware, Software, and Services for Intelligent Building Solutions: Global Market Analysis and Forecasts, Research Report

3. Existing Barriers and threats to the use of AI

Although AI technologies have a huge potential to transform construction sector in a more sustainable, efficient and user-centric industry, there are several barriers to overcome:

- **Lack of ICT skills**. The construction industry has a very positive social impact, because it offers employment opportunities to all socio-cultural levels. Also, it is experiencing an ageing work force, reluctant to changes and with very limited experience in the use of ICT devices and tools. However, this context will be change in the next years, as "*the proportion of low skilled workers declined between 2008 and 2015 across almost all countries*"[46] and the ageing work force is been replaced by a new generation of digital native work force.
- **Short term learning and investment strategy**. The high fragmentation of the value chain and the changes from project to project makes very difficult the development a long-term learning strategy. Consequently, innovation has to be integrated in the construction process very fast and the benefits have to be explicit immediately, in many cases in just one project. Next project will stablish a new value change and perhaps the gained knowledge and equipment's cannot be applied or requires re-training the project team.
- **Low of investment in R&D, especially for the combined use of digitalization technologies**. In line with the previous barrier, the investment in R&D for digitalization in the construction sector is smaller than in other sectors, being crucial the support of the public R&D programs[47].
- **Buildings and civil infrastructures are long term and critical assets**. Typical lifetime of buildings and civil infrastructures is higher than 50 years. At the same time, they have to satisfy very severe safety and security criteria. Consequently, changes in the construction processes can have a very high impact for the facility owners and citizens the sector needs to obtain clear evidences of the long-term impact of the adoption of any innovative technology.
- **Rigid public procurement processes**. The main customer of the construction sector is the administration (transport infrastructures, social houses, hospitals, educational buildings…). Although she is defining new public procurement mechanisms to encourage the adoption of innovative technologies, the process is not fast enough and still the classic and well-known solutions are prioritized. The promotion of pilot cases and dissemination of success stories in the adoption of AI technologies will contribute to create the market for innovative solutions.
- **Social perception of AI as a threat**. AI will impulse a disruptive transformation of buildings and civil infrastructures along their complete life cycle. Although this transformation will bring many advantages in terms of sustainability, efficiency, quality and performances, it can be perceived by the society as a threat. From the labor force point of view, the main concern will be about the suppression of jobs, but from the citizens one the main concern will be about the lack of privacy.
- **Poor adoption of open standards**. The lack of standardized processes and the spread of proprietary data formats and languages could be a threat for implementing AI, increasing the complexity of deploying innovative solutions.

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[46] www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&ved=2ahUKEwjisMq2gcrhAhVQXBoKHRSVCqEQFjACegQIBRAC&url=https%3A%2F%2Fec.europa.eu%2Fdocsroom%2Fdocuments%2F26206%2Fattachments%2F1%2Ftranslations%2Fen%2Frenditions%2Fnative&usg=AOvVaw3D_GQU6w9i1AoQSqlbJHxV

[47] Supporting digitalisation of the construction sector and SMEs. EC DG GROW TG1 Web Meeting, 16 Jan 2019

- **Lack of data**. The lack of available data in the construction sector and the ability to share this between stakeholders will be a massive barrier to the integration of AI in the construction sector. While IoT and Big Data will enable this, the mechanisms to share the data across stakeholders from design to construction to operation needs to be addressed as well as the ownership of the data, the value and quality of the data and the privacy of the data. Approximately two-thirds of the global buildings floor space and more than 90 percent of commercial buildings are small or medium commercial buildings[48] . These buildings typically do not have any Building management system (or having it logged can be delayed) and therefore affects the quantity and quality of the data.
- **Lack of standardized methodologies for data management.** The need for existing methodologies that include a data management plan for the whole project life-cycle and fully compatible the EU General Data Protection Regulation (GDPR) that became effective in May of 2018.

[48] Navigant Research (2016) Executive Summary: Energy Efficiency Retrofits for Commercial and Public Buildings, Research Report

4. Opportunities and Impact

The opportunities and impact for the Construction sector and the Built environment as a whole are obvious at different levels on helping players overcome some of the Construction industry's greatest challenges, including cost and schedule overruns and safety concerns - among others those introduced below:

- Typically, the need for the industry to adopt (and even anticipate) an ambitious policy aligned with the EC climate agenda and how the Built environment can contribute to it, is by **optimising characteristics and behaviours of buildings and infrastructures**, e.g. investing in clean technologies, introducing carbon tariffs, managing in a very detailed way demand/response – all elements that will require more and more data (from BIM, dynamic data from IoT, crowdsensing and crowdsourcing at level of the users, etc.) to be integrated and managed in AI algorithms and solutions: enhanced analytics platforms can collect and analyze (Big) data to understand signals and patterns to deploy real-time solutions, cut costs, prioritize preventative maintenance, etc.; This will allow as well to more swiftly adapt and influence (and in fact anticipate) future government regulations, and the industry champions have a key role to play in a bottom-up approach and promoting AI benefits to the whole sector;
- If the Construction sector wants to fully embrace **circular economy** and all its key Technical cycles - Maintain (Customer), Recycle (Part Manufacturer), Refurbish / Remanufacture (Provider), Reuse / Refurbish (Product Manufacturer), there is as well need to manage huge databases of information related to materials (and in particular innovative material, integrating nanotechnologies, nature-based solutions, etc.) and components and to be able to achieve data analytics, reasoning and decision-making atop these databases: AI and data mining / analytics are key instruments to achieve it
- At last, the built environment is facing an increased demand and urgency to deal with **enhanced resilience**, requiring to deal with problem of uncertainty and needing sound risk assessment and management approaches (in terms of vulnerability, recoverability, and adaptive capacity). Resilience sits in an intricate interplay among individuals, communities, institutions and infrastructures, and involves different dimensions (e.g. technical, cognitive, social) to be elaborated within a complex and rigorous framework: again AI and data analytics tools are instrumental in tackling this complexity, considering Big data and complex algorithms for prediction, simulation and decision-making: predictive applications can forecast project risks, constructability, and the structural stability of various technical solutions, providing insight during the decision-making phase, and enabling testing of various materials, limiting the downtime of certain structures during inspection.
- **Integration of building operations with other emerging technologies** based on IOT sensors, digital assistants (Alexa, Google now, Siri, Cortana…) and distributed encrypted databases (IOTA) to enable synergies to increase the attractiveness of investing into AI in buildings. i.e. IOT + HVAC
- The definitive uptake and generalization of **Off-site construction** with the consequent gains in building time, higher quality with lower investments, less disruption and waste production, will correlate directly with the spread of BIM use and automatization in the construction sector workshops, using laser measurements and robotics. Off-site also needs an important

modernization (digitalization) of the construction supply-chain which is yet mainly organized to answer the needs of a traditional sector.

- New construction design and delivery models, including a strong disruption in the prevalent procurement systems have emerged around **Integrated Project Delivery** methods as a way to improve design and construction processes. Alongside Lean Construction, which has emerged as a cross-sectoral way to apply manufacturing industrial process improvements (originally created by Toyota) to the construction value chain, IPD or its variants like IDDS (**Integrated Design and Delivery Solutions**) have proved, in certain contexts and notably in the USA, that a new, collaborative way of sharing responsibilities and benefits among all the actors of the process, can achieve more quality, reduce waste, time and costs. This trend relies upon and is largely underpinned by digitalization, around the BIM model (furthermore an AI enabled Digital Twin) that can be the shared real-time modifiable support for the collaborative team including non-technical stakeholders, together with efficient and virtualized management tools.

AI techniques and tools have an evident key role to play as well in the development of an intelligent and responsive built environment: to be **responsive to people's needs** including their health and wellbeing, to advance building users preferences, to make easier and reliable the interaction of the building users/owners with the construction value chain (from design to operation and maintenance). The quality of buildings and their environment strongly influences the well-being of their occupants, and indeed EU citizens are waiting for improvement of their health, comfort and well-being in their homes, their offices, their schools, where they spend up to 90% of our time: thanks to fine-grained analysis of data coming from many sources (including crowdsourcing and crowdsensing), AI will provide a huge step ahead in terms of understanding and adapting to people real demand to be fulfilled by reliably smart technologies and resilient housing: Long-term monitoring of indoor environment as well as human behavior and occupant feedback gathering systems will be commonly embedded in the future buildings to fully access the real-time information and conduct artificial intelligence analysis with the big data collection and analytics. As such, AI is identified as providing a large set of instruments to further allow to transform the Construction sector in a citizens-centric one, with the need to finely understand users' behaviors so as to change it or adapt the built environment design for it (*design for all*), and also providing new tools to deal with the complexity of the relationship of intelligent buildings to the infrastructures of towns and cities, with decision making that realizes inputs from all the stakeholders and citizens.

The AEC sector is worth more than $10 trillion a year world-wide, with still an important part in Europe, and with many customers (clients) who want to differentiate and looking for more and more optimised, innovative and sophisticated components, products and buildings, and as such, stakeholders across the project lifecycle, including contractors, operators, owners, and service providers, can no longer ignore getting benefits of AI as technology that is to have a more and more significant role in construction in the coming years.

Technological solutions that incorporate artificial intelligence AI-powered algorithms require a critical mass of data to deliver tangible results: as such, large / lighthouse projects dealing with a significant amount of data to train AI algorithms are likely to be the primary targets of the applications of AI in the construction and built environment sector, with the largest companies / contractors likely to benefit more in the short term. However, those companies, and indeed many firms in the sector, are threatened by one major fact: they have to face the risk that new incoming market entrants represented by the big IT players (the so-called 'GAFA': Google, Amazon, Facebook & Apple) who have the experience of big data management and developing expertise in knowledge learning may take the lead in this capital area, linking the data value chain all over the total life-cycle of buildings and infrastructures. As such, the opportunity here for Construction stakeholders is to not to stay passive, but <u>learn from GAFA and swiftly move on to replicate and customize technology and applications in the construction sector</u>. To play a role in future ecosystems and to be able to compete with these potential new entrants, there is an urgent need for construction companies to catch up in the adoption of AI techniques and market applications, which means allocating more resources to build the AI capabilities, made AI experiments and large-scale pilots, and generate the appropriate training of workers and generation of skills.

Another key point that should support AI take-off in Construction sector is that, by essence and even more today, buildings are indeed integrators of more and more innovative materials, components and technologies coming from many sectors. Typically, modularization and prefabrication is developing fast, leading to off-site construction for large quantities of materials and components, and an increased need for enhanced supply chain coordination AI has a large ability to work across industries, provide with decision-making for optimization of integration and coordination and reducing logistical burdens, enhance risk and safety management, and control of overall costs.

Opportunities are seen in various application areas in the Construction sector, and in the various stages of the building or infrastructure life-cycle:

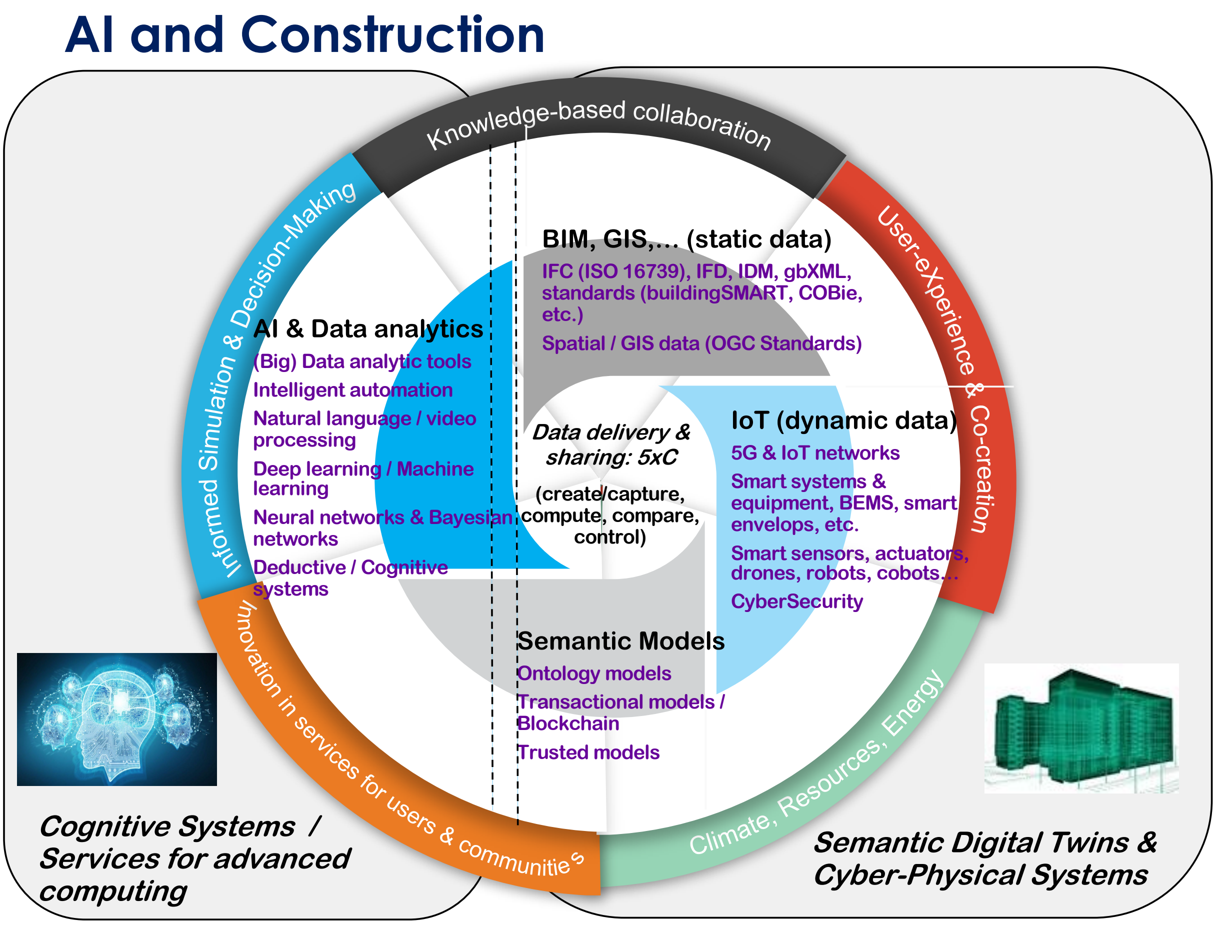
- **Design optimization** – with simulation of various options and potential optimizations, relying on data sensitivity analysis, to improve informed decision at design time according many criteria (construction timeline, likelihood of defective constructions-mistakes during execution and further operation, cost of construction, cost of ownership,…), potentially relying on case-base reasoning, etc.; AI techniques should be applied very early in the design phase, allowing better early design and simulation to avoid re-design and changes later;
- **Optimization of the supply-chain and allocation of tasks and resources** on the Construction site – typically with Digital Twins matching BIM-generated models, dynamic sensors / actuators / drones-based data, and domain-oriented semantic models;
- **Project monitoring** and risk management (including global and site planning);
- **Quality control**, with support to generate contingencies and deploy targeted mitigation plans;
- Support in many aspects related to **operation and (proactive) maintenance** of buildings, infrastructures and, again with AI-based decision-making tools, and including all aspects related to resilience as introduced at the beginning of this section;
- Opportunity for IoT solutions, e.g. affordable wireless sensors that can be placed into the building during construction or after and then also Software as a Service (SaaS) solutions that are simple and designed for the small/medium building with **simple systems filling the gap of lack of BEMs**;
- Transformation of jobs and methods of work: the exploitation of big data pools/lakes provide contents for **new business process**, revisiting the client relationships, improving productivity, dealing with more and more complex regulations - all this by taking advantage from data

(including the huge bunch of unstructured data) and getting a real added value thanks to deep data analytics, deep learning and all IA techniques. In particular, AI tools are to support workers in automating and optimising various tasks (typically content management), as well as client satisfaction (through deep analysis of demands and needs) and knowledge capitalization.

Overall, a first step, which reveals rather urgent, is that Construction firms identify both areas of needs and AI-powered use cases where AI techniques could be integrated and experimented in the short term / middle-term, including with potential pilot projects: this would allow, in a first stage, to better exhibit clear business cases and ROI, identifying where those firms should prioritize their investments based on the areas where AI can have the most impact.

5. Future trends and priorities in application of AI

AI in the built environment is increasingly explored and there is application potential in a wide range of scenarios across disciplines and life cycle stages, as well as across various scales, from building, district, city to wider regional and national levels. Future trends in AI application in the built environment are given below, organized by lifecycle stage. The list below is not comprehensive, but it is indicative of the scale of use of AI in the built environment. Prioritization is concluded in the end.



Planning stage

- Use of AI to predict environmental, demographic, and socio-economic factors around the area of intervention.
- Use of AI to generate project briefs and prediction of potential risks based on past-completed projects.
- Use of machine learning to optimize locations in terms of renewable energy and assess potential (solar, wind, geothermal), as well as the projected carbon footprint of the planned intervention.
- Use of machine learning techniques to predict the infrastructure resilience around the site of intervention.
- Use of AI to predict infrastructure failures and ways to best mitigate these.

- Use of AI to reconfigure mobility and transport nodes and modes surrounding the area of intervention.
- Use of AI to assist in urban planning with a focus on citizen experience and wellbeing.
- Use of AI to factor-in citizens aspirations and views as to the planned development.
- Use of AI for crowd sourcing using the web and social media (relying on tool developed in various media-oriented industries).
- Use of AI to select the design team based on the required skills and competencies.
- Use of AI to empower non-technical stakeholders by "translating" technical and professional data into understandable models and interfaces, and thus ensuring their active participation.

Design Stage

- Use of AI to learn from previous projects and avoid repeating mistakes.
- Use of AI to optimize room and space distribution/layout considering various engineering constraints as well as to optimize the passive attributes of a building, e.g. orientation.
- Use of AI for generative design to explore the variations of a solution and generate design alternatives and select optimal starting points for detailed design.
- Use of AI to optimize infrastructures design giving high-level design criteria, both in materials and in costs. This includes use of AI to design a component/structure in such a way that it can be dismantled and reused in an efficient way, thus promoting a circular, sustainable economy.
- Use of AI to optimize evacuation strategies and minimize the risk of fire, and disasters in general.
- Use of AI to optimize health and safety across the designed building.
- Use of AI to assist with the design process to explore various design options and their consequences and address multi-objective optimization scenarios.
- Use AI to better understand the preferences of building users and providing customized solutions.
- Use of AI in engineering design in areas such as Structure, Mechanical, HVAC, IT and Electrical services to optimize various engineering systems.
- Use of AI to confer models (including BIM-based ones, but not only) developed throughout design a dynamic and self-updating capability, leading to the concept of a dynamic Digital Twin that factors in and pro-actively adapt to various sensory data streams, including intelligent rules based on current construction normative that automatically generates warnings in case of not complying with the regulations.
- Use of AI for automatically determine what the lowest carbon material sourcing it is available in each project.
- Use of AI for optimize the design of the building or infrastructure, including the design of building systems as ventilation, based on the simulation of the behavior of its users.
- Use AI to design a component/structure in such a way that it can be dismantled and reused in an efficient way, thus promoting a circular, sustainable economy.

Procurement Stage

- Use of AI to deliver supply chain optimization: use of supervised learning application for reducing downtimes and oversupply – oriented to mass production (ie, prefabrication / offsite manufacturing).
- Use of machine learning for Biding optimization: per client, per region, per job type, etc…

Construction stage

- Use of AI to check construction compliance to design specification using a wide range of data capture technologies (e.g. 3D Laser scanners, thermal cameras, etc.).
- Use of AI to deliver on-site just-in-time and lean construction methods.
- Use of AI for optimizing construction work scheduling and follow construction progress (off-site & on-site).
- Use of AI to enhance manufacturing using robotics and automated processes in construction sites specially for tasks in extreme working conditions.
- AI-based communication tools to manage the multiple languages of the workers in the construction sites.
- Use of AI increase safety in construction sites through the detection of risky situations.
- Use of AI in construction machinery to optimize earthworks, fuel and time consumption.
- Use of AI to improve fine tune building control setting and improve building commissioning.

Operation Stage

- Use of AI to operate renewable energy systems, such movable Photo-voltaic panels, to maximize energy harvesting.
- Use of AI to manage energy using real-time sensory data (e.g.: weather, occupancy) with a view to continuously reduce the energy gap.
- Use of machine learning to forecasting energy demand and adapt supply accordingly.
- Use of AI to maximize the use of on-site renewable technologies in a multi-vector energy system.
- Use of AI to support energy peer-to-peer sharing communities using emerging models such as Blockchain.
- Use of AI to predict the likelihood of adverse events or failure and promote predictive/proactive maintenance.
- Use AI to detect deficiencies with help of sensors that cannot easily be observed by the naked eye as e.g. corrosion and other deterioration using acceleration monitoring, laser, radar and drones.
- Use of machine learning for automated processes, forecasting change and devising adaptation strategies.
- Use of AI to manage interaction with other components in the district, transport and users (citizens).
- Use of AI to enhance cybersecurity and citizen privacy.
- Use of AI to promote the resilience of critical infrastructures against various natural and man-made threats.

- AI to infer user behavior in buildings and inform building control strategies to enhance the thermal comfort, indoor air quality and energy consumption in buildings.
- Related to ubiquitous computing and sensors, use of AI to promote and generate environmentally and energy virtuous behaviour changes of occupants of buildings ("persuasive technologies").
- Use of AI for video analytics to detect security threats in buildings.
- Use of AI to promote urban intelligence.
- Use of AI to improve the resilience of our urban infrastructures.
- AI to manage and maintenance of the future infrastructure.
- Facility management: data-mining and machine learning to compare the behavior of a building with similar ones.

Decommissioning, demolition and recycling stage

- Use of AI to deconstruct a digital twin and devise the optimal decommissioning strategy.
- Use of AI to devise on optimal strategies to recycle the demolished building.
- Use of machine learning to re-use recycled materials on new projects while ensuring the lowest embodied carbon possible.

<u>Energy Efficient Buildings</u> (EeB): Key challenges and enablers for the successful adoption of AI technologies by the construction sector

- Maintenance, monitoring and operational as the fastest to take-up/bring benefits specially for EE. These will be quicker connecting with other district/urban sub-systems.
- Cybersecurity as critical considering building and infrastructures as a safe environment for citizens to leave and move.
- Gap on Skills/training/education considering the current low-digitalization status (site workers) as well as the lack, for the construction sector, of high-trained IT experts to develop the sector specific applications.
- Regulations and contractual liabilities considering the complexity of the projects and value-chains.
- Development and change of status of our European buildings towards smart buildings, as well as their smart readiness - to transform buildings in "smart-grid ready" / "smart-network ready".
- Deployment of pilot projects to bring new technologies closer to the sector.

ANNEX I

Table 2: Public investments under strategies/initiatives/platforms in the EU Member States

EU Member State	strategies/initiatives/platforms		
Finland	Finnish Artificial intelligence programme	The report Finland's Age of Artificial Intelligence lists eight key actions for taking Finland to-wards the age of AI.	Link
Finland	FAIA – Finland's AI accelerator	FAIA helps Finnish organizations deploy AI. The accelerator is initiated by the Ministry of Economic Affairs of Finland and Finnish technology industries for a time period of 2 years.	Link
The Netherlands	AINED – the national AI Strategy for the Netherlands.	Main actors: TNO, TopTeam ICT, VNO-NCW, ICAI, NWO with support from Boston Consulting Group (BCG) and DenkWerk	Full report (available for download)
The Netherlands	BTIC – the national innovation programme; in relation with DigiDealGO – the national agreement for digitalization of the construction sector	Main actors: TNO; 4TU.Bouw; HBO; professional associations of construction firms, MEP/HVAC firms, and engineering consultants; government ministries of Economic Affairs, Internal Affairs, and Infrastructure and Water Management	BTIC starts on 1 May 2019; DigiDealGO starts on 11 April 2019 (link)
Spain	Spanish RDI Strategy in Artificial Intelligence.	The Spanish RDI Strategy in Artificial Intelligence is the backbone of a vision of RDI that is key for the development of the European framework. This strategy will be the basis for the future National Artificial Intelligence Strategy, which will allow for the coordination and alignment of national investments and policies	Link
Luxembourg	Joint AI laboratory	Luxembourg's research community, the Luxembourg Government, and NVIDIA announced today the creation of a joint AI laboratory in Luxembourg. The national AI collaboration, the first with NVIDIA in Europe, is a milestone towards working together to solving society's most important challenges	Link
France	KROQI Platform, the public and free collaborative work platform for all construction professionals http://www.batiment-numerique.fr/plateforme-collaborative.htm	The French government funded Digital Transition Plan for the Building Sector has gathered multiple stakeholder representation and developed a free to use digital management platform (technical partner CSTB).	

Belgium	The Flemish Minister of Innovation launched in April 2019 the Flemish action plan Artificial Intelligence (AI). The plan includes an annual investment of 32 million euros and focuses on research, implementation, ethics and training. In the framework of Digitalwallonia4.ia, the Walloon Region launched as well a "AI Network" (end 2018) with working groups, seminars, …	Focus on innovation projects for companies (50% of the budget), but also funds for research (both technological as "ethics"). Research and innovation projects with AI-component will higher priority. Global ambition to inform – besides companies – as well 100.000 citizens about the possibilities and benefits of AI. Research centre IMEC (nano electronics and digital technologies) will be leading partner for many projects (all sectors, not sure whether much construction topics will be involved). Flemish Construction Sector and BBRI lead discussion groups about the future of AI for construction.	
Italy	Task Force IA	The Agenzia per l'Italia Digitale - Agency for Digital Italy (AgID) is the technical agency of the Presidency of the Council of Ministers. The task force studies how the dissemination of Artificial Intelligence (AI) solutions and technologies can affect the evolution of public services to improve the relationship between public administrations and citizens.	Link
Italy	S3 Smart Specialization Strategy (National Strategy)	The Department for Development Policies and Economic Cohesion (DPS) of the Italian Ministry of Economic Development (MISE) launched, in agreement with the Italian Ministry of Education, University and Research (MIUR), the project "Support to the definition and implementation of regional policies for research and innovation (Smart Specialisation Strategy)", managed by Invitalia (National agency for inward investment and enterprise development). The goal is to support regional governments in designing and implementing their own SSS through the possibility of sharing, at national level, experiences underway in different regions; The arrangement of the various initiatives of SSS, with the extent of avoiding overlaps between different levels of governance.	Link Link

<table>
<tr><td rowspan="2">Italy</td><td rowspan="2">S3 Smart Specialization Strategy (Regional Strategy)</td><td rowspan="2">ICT development and Digital Agenda implementation – Priority axis 2: it intends to support the use of ICT among businesses to improve their productivity and among public administration to improve its efficiency and, consequently, to offer greater opportunities and benefits to citizens.
ICT is a relevant Key Enabling Technology in the building sector, especially in the field of:
-retrofitting and restoration,
- accessibility, comfort and smart automation of public buildings,
- reduction of seismic risk
- LCA and building process (BIM modelling, augmented reality, IoT, Open Data and Business Intelligence)</td><td>Link</td></tr>
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