# Supporting digitalisation of the construction sector and SMEs

Including Building Information Modelling

**LEGAL NOTICE**

This document has been prepared for the European Commission, however it reflects the views only of the authors, and the Commission cannot be held responsible for any use that may be made of the information contained therein.

More information on the European Union is available on the Internet (http://www.europa.eu).

ISBN 978-92-9202-626-4
doi: 10.2826/422658

# Content

## EXECUTIVE SUMMARY

### *The digitalisation of the construction sector is underway in Europe but at a slow pace*

The digitalisation of the construction sector goes beyond the sole use of BIM (Building Information Modelling) to include automated fabrication (pre-fabrication) using robots and 3D printing, drones, 3D scanning, sensors and Internet of things (IoT). Each of these technologies are slowly penetrating the construction sector in Europe, but so far, the focus on the digitalisation of the construction sector has been on BIM. Nevertheless, seizing the full potential of the digitalisation of the construction sector requires combining BIM with the other digitalisation technologies already in use in the construction sector. BIM is, in fact, the only digitalisation technology mentioned in the EU procurement directive. Furthermore, BIM is the only digitalisation technology required for use, on mandatory basis, for public works and design in eight Member States (Austria, Denmark, Finland, Germany, Italy, Luxembourg, Spain and the United Kingdom). With up to 98% of its construction chain composed of SMEs and micro-enterprises characterised by decreasing innovation activity, low rates of technological adoption and decreasing efficiency, digitalisation of SMEs in the construction sector is strategic for the EU.

### *The challenges to a fully digitalise the construction sector*

The digitalisation of the construction sector faces a variety of challenges. Some of these are not specific to the sector, such as data security and preparedness to cyber-attacks, but are common to all segments of the economy. This study has identified 10 main challenges or gaps as a result of desk research and expert validation interviews.

### *EU's construction industry is not digitising at the same speed as major construction markets*

Overall, the digitalisation of construction is accelerating in global construction markets, especially regarding the uptake of BIM. However, the EU construction market ranks fifth in the use of BIM, while the North American market is leading. Consequently, the North American market is also leading in terms of expertise and skilled staff. At a global level, the French construction market is leading in the use of BIM for civil engineering works and electricity activities. The British construction market is leading, in the EU, in the use of BIM for institutional buildings- a positive impact of the digitalisation targets introduced in the British procurement rules.

### *Recommended actions to improve the current situation of the construction sector*

This report also presents an overview and brief descriptions of the recommended actions to improve the current state of digitalisation of the construction sector. In total, 10 actions with several sub-actions are proposed through this study. Three of these are suggested to be prioritized by the European Commission and executed within three years in cooperation with stakeholders from the construction industry, such as larger companies and SMEs, umbrella organisations, and Digital Innovation Hubs (DIHs). These actions are:

i. Introduction of an interactive handbook and digital maturity scan for the adoption and implementation of digital technologies by construction SMEs
ii. Support to DIHs to accelerate the digital transformation.
iii. Provide lifelong (Digital) skills development for (blue collars) employees within the construction sector through trainings.

This report concludes that a digital transformation of the construction sector requires:

- Effective cooperation between the partners from:
    1) the industry,
    2) knowledge and research institutes, and
    3) the government.
- Synergies between regional and national initiatives from various EU Member States, allowing regions to build on their strengths and focus on their niches to become complementary to other regions.

# INTRODUCTION

Digitalisation of the economy is one of the priorities set by the European Union (EU). The Strategy for a Digital Single Market[1], developed by the European Commission (EC) in 2015, outlined the path for the EU to build the right digital environment. This strategy included several initiatives such as the development of digital platforms, the digital skills agenda, standardisation, as well as the development of several legislative proposals. The aim is to maximise the growth potential of the digital economy in Europe and to ensure European industries are at the forefront of developing and exploiting digital technologies of the markets of the future. The mid-term review of the implementation of the Digital Single Market Strategy[2], published in 2017, shows that an important progress was made in digitalising Europe. However, still a lot needs to be done to ensure the EU industry will fully seize the digitalisation opportunities. This is particularly true in sectors, such as the construction sector, which is highly dominated by Small and Medium Enterprises (SMEs) and ranking as the second less digitised sector globally, right after agriculture.

The construction sector is one of the pillars of the EU economy. The value added from the sector was €534 billion in 2015[3], which was equivalent to 7% of the EU non-financial business economy[4]. The construction sector employed, in the same year, more than 12 million people. This was equivalent to 8.8% of the total employment of the EU non-financial business economy. Within the construction sector, specialised construction activities[5] contributed 57% of the total value-added and generated 63% of the total employment.

The construction sector is characterised by a high number of micro-enterprises. Enterprises with less than nine employees represented 94% of all enterprises active in the sector, while large enterprises represented less than 0.5%. From a labour productivity perspective, the sub-sector of specialised construction activities had the lowest one in 2015 with gross-value added per person employed at €39,000 against €53,000 in the civil engineering sub-sector and €48,000 in the construction of buildings sub-sector. The same year, the apparent labour productivity of the manufacturing sector was at €62,000 per person employed. Furthermore, the average investment in research and development in the construction sector was, in 2015, at €2.3 per inhabitant against €181 per inhabitant in the manufacturing sector[6].

In a Manifesto[7] published in June 2018, the European Construction Industry Federation (FIEC) with other major European construction industry associations, acknowledged the role of digital technologies in improving productivity, reducing project delays, improving safety, offering better working conditions, providing affordable homes, and enhancing the quality of buildings and infrastructures. The Manifesto called for a strong EU leadership in the digitalisation of the

---

1 European Commission: A Digital Single Market Strategy for Europe, COM 2015 (192) https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52015DC0192&from=FR

2 European Commission: Mid-term review of the Digital Single Market Strategy for Europe, COM 2017 (228) https://eur-lex.europa.eu/resource.html?uri=cellar:a4215207-362b-11e7-a08e-01aa75ed71a1.0001.02/DOC_1&format=PDF

3 The latest year for which all EUROSTAT data used in this report exist

4 EUROSTAT, Structural Business Statistics (SBS) database http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=sbs_na_sca_r2&lang=en

5 site preparation (including demolition and earth moving); installation activities (installation of electrical wiring and fittings, heating systems, plumbing, elevators and insulation); completion and finishing activities (plastering, joinery, flooring, glazing or painting); other specialist activities, such as, roofing, pile driving, scaffolding.

6 EUROSTAT, Business Expenditures on R&D http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=rd_e_berdindr2&lang=en

7 FIEC, Joint Manifesto on Digitalisation from the Construction Industry http://www.fiec.eu/en/library-619/joint-manifesto-on-digitalisation-from-the-construction-industry.aspx

construction sector by developing the appropriate regulatory framework on data policy, facilitating and supporting research and development as well as investing in IT infrastructure and upgrading skills. Digital technologies considered by the construction industry include Building Information Modelling (BIM), cloud storage, 5, 6, 7+D design, automated fabrication (pre-fabrication) using robots and 3D printing, big data analytics including data ownership and access, Artificial Intelligence (AI), a new wave of voice recognition systems, as well as intelligent buildings and smart cities. McKinsey[8] also advocates for digitalisation as means to tackle current challenges such as the growing complexity and size of construction projects, the growing demand for sustainable construction and the shortage of skilled labour.

The importance of requiring the use of digitalisation technologies in the construction sector was recognised in the EU procurement directive of 2014[9]. Since the adoption of the directive, several EU initiatives (e.g. BIM task group, H2020 support to research and uptake) have been implemented and some Member States made the use of Building Information Modelling (BIM) mandatory for public works and design contests. However, the directive and the existing initiatives at EU and national level focus on the use of BIM while seizing the full potential of BIM requires combining it with other digitalisation technologies (3D printing, drones, 3D scanning, automated robots, sensors and Internet of things (IoT).

This study was commissioned by the Executive Agency for Small and Medium Enterprises (EASME) to assist the European Commission in developing a blueprint for EU actions to support the acceleration of digitalisation (BIM and other technologies) of the construction sector SMEs.

The research was carried out in stages. Firstly, desk research was carried out to identify the digital technologies relevant to the construction sector and to assess their use per construction sub-sector. In the absence of data on the penetration of each digital technology, the desk research assesses the gaps in the use of BIM between three European countries (France, Germany and the United Kingdom) and other major construction markets (USA, Canada, Brazil, South Korea, Japan, Australia and New Zealand). The desk research concludes by discussing the identified gaps to the digitalisation of the construction sector. The following step of the research focussed on confirming the conclusions of the desk research through expert interviews. Recommendations drawn from the desk research and expert interviews will be considered, in the next step, for the selection of the actions relevant for EU intervention. The selected actions will be further developed in the following step. Finally, a roll-out plan, to ensure effective implementation of the selected actions, will be proposed by the Consortium to the Commission.

The report is structured as follows:

- Chapter 1: Desk research
- Chapter 2: Expert interviews
- Chapter 3: Recommendations and selection of actions.
- Chapter 4: In-depth assessment of the selected actions.
- Chapter 5: Roll-out plan for the implementation of the selected actions.

[8] McKinsey & Company (2016) Imagining construction's digital future

[9] EU Directive (2014/24/EU) of the European Parliament and of the Council of 26 February 2014 on public procurement https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0024&from=en

# CHAPTER 1: DESK RESEARCH

This chapter provides a snapshot of the status of the digitalisation of the construction sector in the EU28 based on the desk research conducted by the consortium in summer 2018 using most recent data and studies. The aim is to identify, where data and information is available, the digitalisation gaps per construction sub-sector, construction phase and country.

## 1.1. Classification of construction activities in the Nomenclature of economic Activities of the European Community (NACE)

The construction sector is defined in NACE 2 by three sub-sectors. Each of which varies in terms of targeted market segment, employment size and its contribution to the construction sector output as data from EUROSTAT[10] show in the following paragraphs:

- The sub-sector of construction of buildings includes the development of building projects and the construction of residential and non-residential buildings. In 2015, the value-added from this sub-sector was €149 billion, which was equivalent to 28% of the total construction sector output. The construction of buildings employed, in the same year, 3.1 Million people, which was equivalent to almost 26% of total employment in the construction sector. Enterprises with less than nine employees represented 94% of all enterprises active in this sub-sector, while large enterprises (with 250 persons employed and more) represented less than 0.05%.

- The civil engineering sub-sector includes the construction of roads, railways, utility projects and other civil engineering projects. In 2015, the value-added of this sub-sector was €82 billion, which was equivalent to 15% of the total construction sector output. Civil engineering employed, in the same year, 1.5 million people, which was equivalent to 12% of total employment in the construction sector. Enterprises with less than nine employees represented 81% of all enterprises active in this sub-sector, while large enterprises (with 250 persons employed and more) represented less than 0.8%.

- The sub-sector of specialised construction activities is complementary to the two previous sub-sectors. In fact, specialised construction activities include i) demolition and site preparation activities, ii) electrical plumbing and other construction activities, iii) building completion and finishing and iv) other specialised construction activities such as the renovation of buildings and upgrade of infrastructures. In 2015, the value-added of this sub-sector was worth €303 billion, which was equivalent to 57% of the total construction sector output. Specialised construction activities employed, in the same year, 7.7 Million people, which was equivalent to almost 63% of total employment in the construction sector. Enterprises with less than nine employees represented almost 95% of all enterprises active in this sub-sector, while large enterprises (with 250 persons employed and more) represented less than 0.03%.

Data on investment in research and development per sub-sector was not identified in EUROSTAT databases. Similarly, data on skills upgrade was not identified in EUROSTAT databases, neither for the overall construction sector nor for the sub-sectors.

---

[10] ibid

## 1.2. Desk research methodology

The desk research was conducted between May and October 2018. The online platforms used, for the identification of the literature to review, included Science Direct[11], CORDIS database for EU funded projects[12], Construction 21[13] and other web platforms such as those specialized in providing news related to the construction sector[14].

Keywords used to identify the relevant literature to review included: digitis(z)ation, digitalis(z)ation, automation, prefabrication, robots, Building Information Modelling (BIM), Geographical Information System (GIS), Asset Information Model (AIM), additive manufacturing, 3D-printing, Unmanned Aerial Vehicle (UAV), drones, 3D scanning, sensors and Internet of Things (IoT).

The full list of the literature reviewed is included in Annex A of this report. The literature examined consists of the following material:

- 130 papers published in peer-reviewed journals.
- 38 reports from international organisations and consulting firms.
- 11 reports from European Institutions.
- More than 1000 EU funded individual projects.
- 26 presentations from conferences/workshops.
- 20 online articles.
- 10 position papers from industry groups.

The focus was on SMEs and micro-enterprises. The literature review was narrowed down to publications from 2014 and onwards, as it was not expected that pre-2014 publications would provide constructive information, since terms like BIM, 3D printing and drones are only recently being broadly mentioned in the construction sector. The literature identified was reviewed with all construction sub-sectors (see previous section) and all construction phases (planning and designing, procuring and constructing, producing, operating, maintaining as well as demolishing) in mind. The aim was to identify, per sub-sector and per construction phase, leading countries in digitalisation and those lagging. The overall objective was to spot, for the European Commission, factors of success that would contribute to accelerating the digitalisation of SMEs in the construction sector. However, given that the digitalisation of the construction sector is an emerging issue in the EU, the scope of the investigation has been shrunk to the identification of digitalisation technologies relevant to the construction sector and to assessing the level of penetration of each identified technology per sub-sector. This assessment was conducted based on established use-case per technology and where information available per sub-sector. Moreover, the gaps between EU countries and other major construction markets was assessed only for BIM due to a lack of data and information in the identified literature as described in the following sections.

## 1.3. Digitalisation technologies relevant for the construction sector

The literature reviewed suggests that mainly seven digitalisation technologies are used main in the construction sector. For the purpose of this report, digitalisation of the construction sector

11 https://www.sciencedirect.com/
12 https://cordis.europa.eu/projects/en
13 https://www.construction21.org/
14 e.g. http://www.ebc-construction.eu/

is defined as the use, in one of the phases of a construction project, of at least one of the digitalisation technologies described below:

1. **BIM, e.g. Building Information Modelling or Building Information Management** which is a concept that is a special case of the more generic Asset Information Modelling (AIM), both of which covering the whole lifecycle and supply-chain of an asset[15] (e.g. a building or infrastructure). BIM and the supporting software tools can integrate or link the typically 3D modelling work of architects, engineers, manufacturers in one single model. Changes made by one actor involved in the project will automatically be used to update the other sections of the project by other actors. The popularity of BIM in the construction sector is increasing[16]. Literature suggests that the terms BIM and AIM are understood differently by stakeholders, which may lead to misunderstandings about their respective roles.[17] However, there seems to be an agreement in the literature about the positive impacts of the use of BIM/AIM on, for instance, reducing costs by allowing for early collaboration, which leads to less errors during the construction phase. Thus, construction delays and material waste are reduced. This seems to be particularly true if BIM/AIM is coupled with new advanced and emerging software functionalities like machine learning[18] and bots[19].

2. **Additive manufacturing (3D printing)** is the process of creating an object by solidifying a raw material (e.g. plastic, metal, wood or concrete) under the control of a computer using a Computer-Aided Design (CAD) or BIM file to guide the 3D printer nozzle. 3D printing minimises material waste, reduces the duration of the construction phase as well as labour accidents. If coupled with automated robots, 3D printers could lead to fully automated prefabrication processes which turn a 2D drawing or 3D model into prefabricated and standardised construction components[20].

3. **Robotisation** in the construction sector consists of the use of devices with robotic arms which operate repetitive processes such as laying floor tiles or bricks, lifting heavy objects and placing them in exact coordinates. Bricklaying robots, welding robots and self-driving heavy machinery make construction safer, faster while reducing construction costs. Furthermore, robots could be paired with humans to assist them in tasks that would take a human worker more effort or to improve the mobility of workers with injuries which otherwise would not work in the construction sector[21]. More innovation is expected to come regarding coupling robots with drones to enable field augmentation[22].

4. **Drones** are unmanned aerial vehicles equipped with high-resolution cameras and other scanning equipment. Drones can scan large areas or different directions/angles of an object simultaneously. Drones provide live streaming videos/photos for BIM use. Thus, allowing for reality-capture solutions and real-time comparison between planned and implemented solutions. The dynamic view of construction projects allows for faster adaptation of each part of the project to the new reality by the relevant stakeholder. If coupled with IoT, 3D models

---

[15] INTERLINK, https://roadotl.geosolutions.nl/static/media/INTERLINK_D2_D3_Poster_Final_Issue.pdf
[16] EUROTL framework overview, https://roadotl.geosolutions.nl/publications/
[17] Vass & Gustavsson (2017), Challenges when implementing BIM for industry change. http://dx.doi.org/10.1080/01446193.2017.131451
[18] J.L. Blanco (2018), Seizing opportunity in today's construction technology ecosystem. https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/seizing-opportunity-in-todays-construction-technology-ecosystem?cid=soc-web
[19] Bots are software services intended to automate simple tasks that require processing information and management.
[20] Ibid
[21] Ibid
[22] Ibid

generated by drones would allow for a better monitoring and inspection of construction projects.

5. **3D scanning** is the process of creating a 3D model of a real-world object or construction by scanning it from all possible angles. This process can be used in the construction sector for creating 3D models of existing buildings and infrastructures for which there is no digital information. The use of 3D scanners is, quite often, enabled by the use of drones. The 3D images captured by 3D scanners are incorporated in BIM for further elaboration and use with the information already available in the model. Thus, allowing for an accurate intervention on existing buildings and infrastructures.

6. **Sensors** offer the possibility of continuously collecting data and monitoring the performance of an aspect of a construction (e.g. electricity consumption, indoor air temperature, $CO_2$ concentration). The use of sensors facilitates the transition from planned maintenance towards predictive maintenance leading to cost reductions and reduced disturbance for the users. This is particularly true if sensors are coupled with IoT which can alert project managers about the need for an early intervention.

7. **IoT** is the concept of connecting to the internet household appliances, devices, sensors, vehicles, etc. Thus, allowing for communication, remote control, exchange of data, etc. IoT is, currently, closely related to sensors as in most cases it requires some form of data provided by the sensors. However, as mentioned earlier, IoT could also be coupled with drones and 3D scanners which would lead to a better monitoring and inspection of construction projects.

BIM is the binder which links the other six digitalisation technologies for an optimum use of each of them. The combined use of these technologies should boost the productivity of the construction sector. However, the methodologies and data used to assess the expected improvement of productivity not identified in the literature.

Standardization and interoperability are crucial for the digitalisation of the construction sector. Various standardization organizations are working on this topic.[23] Formal international standardization for BIM is organized by ISO. (e.g. ISO TC59 / SC13 "Organization and digitization of information on buildings and civil engineering, including building information modelling (BIM)" and TC184: "automation systems and integration") and on European level by CEN (e.g. TC442). In addition to formal standardization, there are also informal standardization initiatives in this field such as the buildingSMART International (bSI) initiative that developed the Industry Foundation Classes (IFC) as a neutral and open specification for the BIM data model and they maintain it, or the Open Geospatial Consortium (OGC) for GIS standards. GIS standards are open standards for the global geospatial community including the built environment. Another example of an informal initiative is the World Wide Web Consortium (W3C) that focus on underlying web technology.

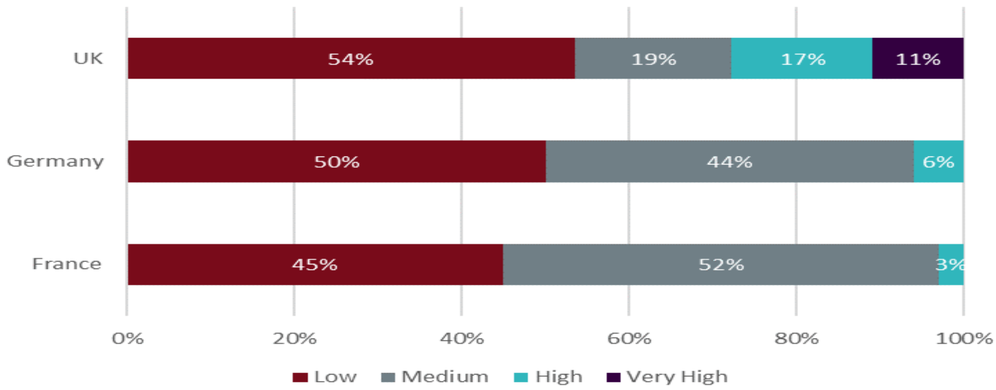
### 1.4. Market penetration of digitalisation technologies in Europe

Data on market penetration of the technologies identified above is rather scarce. Quantitative data was not identified in the literature while qualitative data based on surveys and interviews from construction companies is emerging, especially for the use of BIM.

[23] http://publications.jrc.ec.europa.eu/repository/bitstream/JRC109656/jrc109656_bim.standardization.pdf

Interviews conducted with leading construction companies in Europe show that the digitalisation potential is not yet fully exploited in the sector. In fact, only 6% of construction firms reported making a full use of digital planning tools. In addition, all the building material companies interviewed consider that they have not yet exhausted their digital potential.[24] This survey confirms the results of an earlier survey[25] about the use of BIM, conducted with over 700 construction companies / contractors in ten leading construction markets, among which in France, Germany and the UK in the EU. In France, Germany and the UK, around 50% of the interviewees consider their level of engagement in the use of BIM low (Figure 1). However, the number of interviewees reporting high to very high engagement varies across countries. French and German companies seem to be lagging compared to the British ones. In fact, none of the French and German companies reported very high engagement in the use of BIM while 11% of the British companies did. Moreover, only 3% of the French companies reported a high engagement in the use of BIM, against 6% in Germany and 17% in the UK (Figure 1).

**Figure 1: Share of companies based on the level of engagement in the use of BIM[26]**




The low engagement in the use of BIM by construction companies is confirmed by the lack of investment in digital tools. The first step towards the digitalisation of any sector is having access to the internet (e.g. via tablets, smartphones or computers). In construction, although it is a sector where activities take place at the same time offsite and onsite and require continuous updates and information flow in both directions, this is not the case. In fact, in a survey conducted with nearly 40 companies of all sizes in Germany, Austria and Switzerland, from 29% of the companies interviewed less than 40% of employees have access to computers and internet. Moreover, in 12% of the surveyed companies less than 20% of employees have access to computers and internet. Based on this survey, the high penetration (more than 80% of employees) of computers and internet was reported only in 41% of the companies surveyed. Similarly, the use of tablets and smartphones is rather rare. In fact, the high penetration of tablets and smartphones (more than 80% of employees) was reported only by 12% of the companies interviewed (Figure 2).

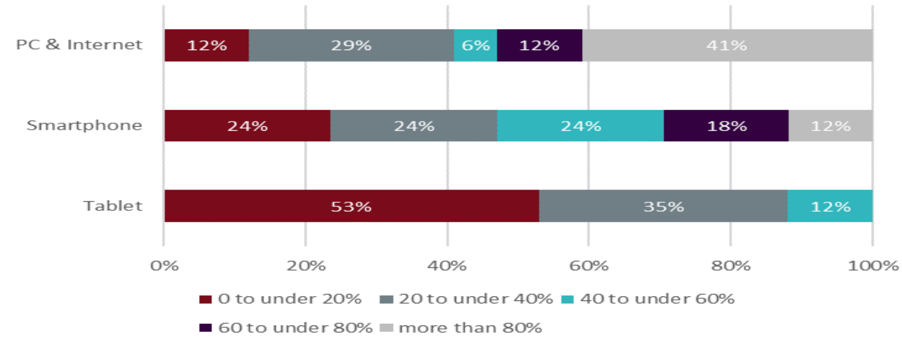
---

[24] Roland Berger (2016), Digitization in the construction industry. www.rolandberger.com/en/Publications/pub_digitization_of_the_construction_industry.html

[25] McGrawHill (2014), The business value of BIM for construction in major global markets. www.icn-solutions.nl/pdf/bim_construction.pdf

[26] McGrawHill (2014), The business value of BIM for construction in major global markets. www.icn-solutions.nl/pdf/bim_construction.pdf

**Figure 2: Share of companies based on the percentage of employees who have access to a computer[27]**




Construction sector workers are typically not knowledgeable or lack access to digital tools that could facilitate their work. This exacerbates the problem, showing that a need for a skills upgrade and facilitation of access is evident.

[27] Ibid

### 1.5. Established use-case of digitalisation technologies per sub-sector

An established use-case of digitalisation technologies per sub-sector could be used as a proxy to assess the potential use of each of the identified technologies per construction sub-sector as shown in Table 1.

**Table 1: Selected established use case of digitalisation technologies per construction sub-sector**

| Digitalisation technologies | Construction sub-sectors | | |
|---|---|---|---|
| | **Construction of buildings** | **Civil engineering** | **Specialised construction activities** |
| BIM | The comparison of the current architectural model with the current "as-built" BIM structural model and the current sub-contractors' models allowed early detection of collisions in several building projects (e.g. Barts and the Royal London Hospital, Commercial development projects in Helsinki…[28]. | The underground rail project under construction in the greater London area consists of 1.7 million CAD files that are integrated in a set of linked BIM databases[29] allowing for a more accurate design. | Plumbing and lighting industries are creating 3D models of their products in databases such as BIM object[30] to make them available for design teams. |
| Additive manufacturing (3D printing) | The first 3D printed non-residential building in Europe was inaugurated in Denmark in 2017.[31] | A 3D-printed concrete cyclist bridge was recently inaugurated in the Netherlands.[33] A steel 3D-printed pedestrian bridge is planned in one of Amsterdam's canals[34]. | A 3D printer allowed restoring historical buildings in Rotterdam by printing ornaments like the original ones[35]. |

[28] BIM projects, https://group.skanska.com/about-us/building-information-modeling-bim/bim-projects/

[29] Boston Consulting Group (2016), Digital in engineering and construction. futureofconstruction.org/content/uploads/2016/09/BCG-Digital-in-Engineering-and-Construction-Mar-2016.pdf

[30] https://bimobject.com/en/product

[31] 3DPrinthuset (2017), The construction of Europe's first 3D printed building has begun and is almost complete. https://3dprinthuset.dk/europes-first-3d-printed-building/

[33] The Guardian (2017), World's first 3D-printed bridge opens to cyclists in Netherlands. https://www.theguardian.com/technology/2017/oct/18/world-first-3d-printed-bridge-cyclists-netherlands

[34] De Zeen (2018), Robots complete span of 3D-printed bridge for Amsterdam canal. https://www.dezeen.com/2018/04/17/mx3d-3d-printed-bridge-joris-laarman-arup-amsterdam-netherlands/

[35] Rotterdam uses 3D printing for construction: costs are reduced with 70%

| | | | |
|---|---|---|---|
| | The first 3D printed houses in Europe should be delivered in 2019 in the Netherlands.[32] | | |
| Automated robots | Automation is used to produce offsite lightweight insulated structural panels that are assembled within 3 to 5 days to produce fully prefabricated homes[36]. | Several prefabricated bridges using different materials (concrete, steel, timber…) are already in use in the UK[37]. | Automation allowed producing offsite prefabricated building solutions that include walls, roofs and technical energy system. These solutions are used to renovate social housing to net zero energy consumption[38]. |
| Drones | Drones were used in Cambridge to report on the progress made in the construction of new buildings. Photos and videos provided by the drones were reviewed and analysed back to back by the project team, which allowed for faster implementation of the necessary adjustments[39]. | Drones are used in the UK for the construction of infrastructures such as airports, bridges or railways[40]. Drones used for infrastructures are usually equipped with sensors for the transmission of high definition photos and videos, thermal imaging, infrared sensors, Lidar and obstacle avoidance technology, amongst others. | A quadcopter (drone) was utilised for automating asphalt pavement inspection and identifying cracks on the asphalt surface.[41] COWI has formed a drone inspection team, assigned to inspect the condition of bridges, especially locations that are hardly accessible.[42] That would minimise the need for the use of rope |

https://tractus3d.com/renovation-costs-reduced-by-up-to-70/

32 Quartz (2018), The first 3D printed houses for rent will be built in the Netherlands this year. https://qz.com/1298963/the-first-3d-printed-houses-will-be-built-in-the-netherlands-this-year/

36 https://www.prefabhomes.eu/

37 https://www.beaverbridges.co.uk/beaver-bridges-by-type

38 Platform 31, https://www.platform31.nl/

39 Drones in the construction industry http://skyflyvideo.co.uk/blog/drones-in-construction

40 The use of drones in construction: a different way of working https://blog.ferrovial.com/en/2016/05/drones-in-construction-a-different-way-of-working/

41 Zakeri (2016), Rahbin: A quadcopter unmanned aerial vehicle based on a systematic image processing approach toward an automated asphalt pavement inspection. http://dx.doi.org/10.1016/j.autcon.2016.09.002

42 COWI (N/A), Bridge operation & maintenance.

| | | | |
|---|---|---|---|
| | | | access team which poses a great risk of accidents. |
| 3D scanners | Not identified in EU projects | COWI has developed a 3D-scanner that can create 3D models of existing infrastructure such as tunnels.[43] | 3D scanners were used for the renovation of social housing in the Netherlands (Energiesprong project). This allowed producing 3D drawings of the existing buildings which were used later for the prefabrication of the renovation kits. |
| Sensors | Not identified in EU projects | The six-lane, 2.9 km Charilaos Trikoupis Bridge in Greece is outfitted with 100 sensors (accelerometers, strain gauges, anemometers, weigh-in-motion devices and temperature sensors) that monitor its condition[44]. | In the residential area of Nordhavn in Denmark, sensors are implemented in the concrete slab to measure the heat transfer from outside to the inside and vice-versa and to monitor the performance of the floor heating.[45] |
| IoT | Not identified in EU projects | Not identified in EU projects | The new headquarters of Deloitte, “Edge”, in Amsterdam is an office building using IoT in the use phase. Building users have an app on their smartphone that can direct them to a parking spot, they can book desks and meeting rooms and adjust the indoor environment based on their personal preferences.[46] |

[43] COWI (2018), 3D models of infrastructure will soon be a prerequisite for maintenance work. https://www.cowi.com/insights/3d-models-of-infrastructure-will-soon-be-a-prerequisite-for-maintenance-work
[44] Smart roads -Wireless Sensor Networks for Smart Infrastructures: A billion-dollar business opportunity http://www.libelium.com/smart_roads_wsn_smart_infrastructures/
[45] http://www.nordhavnen.dk/english/uk-nh-transformation2/uk-nh-newhomes.aspx
[46] BPIE (2017), Is Europe ready for the smart building revolution? http://bpie.eu/publication/is-europe-ready-for-the-smart-buildings-revolution/

Compiling the data provided in Table 1 was fastidious because most of the projects described in the literature are located outside Europe.

### 1.6. Market penetration of digitalisation technologies in major global construction markets

Market penetration of digitalisation technologies in major global markets was not identified in the literature. However, a survey, published in 2014[47], gathered data from 727 companies active in ten leading construction markets including France, Germany, the UK, the US and Canada, Brazil, South Korea and Japan as well as Australia and New Zealand. Unfortunately, the focus of the survey was only on the use of BIM. The survey was updated, in 2017[48], with a special focus on the use of BIM in transportation infrastructure. The geographical scope of the 2017 edition was narrowed down to the US, France, Germany and the UK.

Overall, the usage of BIM in construction projects is accelerating in global construction markets. However, construction companies active in the North American market reported the highest use of BIM. The European construction market is the fifth market for the use of BIM. Regarding the level of expertise; as it can be expected, the higher is the penetration of the usage of BIM, the higher is the level of expertise. In fact, Canada and the US reported the highest levels of expert and advanced users of BIM. In the European market, companies active in the French market reported the highest levels of experts and advanced users of BIM (Annex A).

The use of BIM per construction sub-sectors varies across the ten leading construction markets. Companies active in the French market reported the highest proficiency levels in the use of BIM for civil engineering works, followed by those active in the Japanese market. Regarding the sub-sector of construction of buildings, companies active in the Japanese market reported the highest proficiency level for the construction of steel buildings, followed by the companies active in the French market. Companies active in the French market reported the highest proficiency level in the use of BIM for electricity activities, followed by the companies active in the German market. While companies active in the US market reported the highest proficiency level for the use of BIM for plumbing, mechanical and sheet metal activities (Annex A).

Moreover, surveyed companies reported on their use of BIM per construction projects type. The survey shows that the strongest use of BIM occurs for the construction of commercial buildings. The highest share of the companies using BIM for institutional buildings was in the US, followed by the UK. This might be due to the British procurement rules (see next section). Similarly, the highest share of companies reporting the use of BIM for the construction of public buildings was in the US, followed by the UK (Annex A).
The survey provides insight about the use of BIM per companies' size. Large companies reported very high use of BIM, while small companies reported very low use of BIM. This suggests that the size of the company might be a barrier to digitalisation.

---

[47] Ibid
[48] https://www2.deloitte.com/content/dam/Deloitte/us/Documents/finance/us-fas-bim-infrastructure.pdf

## 1.7. EU support to the digitalisation of the construction sector

### 1. Policy framework:

From a policy perspective, the EU directive (2014/24/EU)[49] on public procurement is the only policy instrument that clearly refers to the use of digitalisation technologies in the construction sector. However, BIM is the only digitalisation technology mentioned in the procurement directive. In fact, Article 22 of the directive stipulates that "*For public works and design contests, Member States may require the use of specific electronic tools, such as of building information electronic modelling tools or similar".*

The transposition of the directive at national level varies greatly across Member States. As shown in Figure 6, eight Member States (Austria, Denmark, Finland, Germany, Italy, Luxembourg, Spain and the UK) have made the use of BIM mandatory in public procurement while countries like France have launched national initiatives to encourage the use of BIM instead of requiring it in public procurement[50].

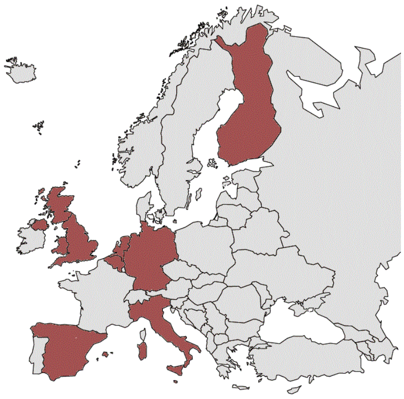
It is worth noting that the UK has adopted the use of BIM for public projects prior to the adoption of the 2014 EU directive[51] on procurement. In fact, the first British requirement for the use of BIM goes back to 2011 for Level 1 use[52] (i.e. using 3D and 2D CAD files). This was followed, in 2016, by requiring Level 2 for the use of BIM (i.e. using 3D CAD models, working on a single, shared model and having common data to enable carrying out checks). Furthermore, the UK plans to advance to Level 3 use of BIM (i.e. full collaboration among all disciplines, using a single shared project model held in a central repository) by 2019.[53]

The level of engagement in the use of BIM by the British companies highlighted in the previous section (28% of the companies reported high to very high engagement in the UK against 6% in Germany and 3% in France) and the leading use of BIM for different projects type by the companies active in the UK, might well be due to the requirement for the use of BIM in public procurement in the UK.

---

[49] Ibid
[50] www.batiment-numerique.fr/
[51] Ibid
[52] Mills (2016), The current state of UK BIM adoption. www.theb1m.com/video/the-current-state-of-uk-bim-adoption-autumn-2016-john-eynon
[53] Roland Berger (2017), The disruptive impact of Building Information Modeling (BIM). Available at: www.rolandberger.com/en/Publications/pub_disruptive_impact_of_building_information_modelling.html

**Figure 3: European countries who have made the use of BIM in public procurement contracts mandatory[54]**



## 2. EU BIM Task group

Two years after the adoption of the 2014 EU directive on procurement, the EC established an "EU BIM Task group". The aim was to develop a common European network on BIM and to align the use of BIM in public works. The task group published a handbook to facilitate the use of BIM by the European public sector.[55] The handbook includes procurement measures, technical considerations, skills development; and 21 case studies on the use of BIM gathered from different MS. The handbook highlights the leading role of public authorities in the digitalisation of the construction sector and the need for collaboration among different stakeholders.

The EU BIM task group was a good step forward. Similarly, the handbook is a useful tool that provides a good introduction to the use of BIM in public procurement. However, the lack of data and evidence, about the digitalisation of the construction faced by the Consortium, suggests that additional efforts and may be different forms of EU support are needed.

## 3. EU support to skills upgrade and research

a. Support to skills upgrade

The BUILD-UP skills[56] initiative is an EU project implemented, since 2011, under the framework of the Intelligent Energy Europe (IEE) programme. The aim of the initiative is to unite forces and to increase the number of qualified workers in the building workforce in Europe. BUILD-UP Skills focuses on the continued education and training of craftsmen and other on-site workers in the field of energy efficiency and renewable energy in buildings.
Since the launch of the BUILD-UP Skills initiative, more than 100 training materials have been developed and were provided either online or onsite. However, none of these training

[54] Ibid
[55] EU BIM Task Group (2017), Handbook for the introduction of Building Information Modelling by the European Public Sector. www.eubim.eu/wp-content/uploads/2017/07/EUBIM_Handbook_Web_Optimized-1.pdf
[56] http://www.buildup.eu/en/skills

materials is about the use of one of the identified digitalisation technologies, nor about introducing the concept of digitalisation. Given the success of the BUILD-UP[57] skills initiative, it would be wise including trainings on the use of the digitalisation technologies identified in this report.

b. Support to research

Under H2020 framework, the EU provides support to research digitalisation in the construction sector. The full list of EU funded projects is available in the CORDIS[58] database. More than 1000 projects related to research in digitalisation were identified, out of which 51 projects are directly related to the digitalisation of the construction sector (Annex B).

It is worth noting that the number of projects related to the digitalisation of the construction sector increased from 3 projects in 2014, which was equivalent to a total EU contribution of €11 Million; to 21 projects in 2017, which was equivalent to a total EU contribution of €45 Million. The total EU contribution to research on the digitalisation of the construction sector, since 2014, is equivalent to €139 Million.[59]

The evaluation of the impact of EU investment on the digitalisation of the construction sector is not possible at this stage as most of the projects identified are still ongoing. However, the description of the projects included in the CORDIS database shows that research on buildings dominates research in civil engineering, dealing with the built environment including not only buildings, but also public works from roads and bridges, to railways and airports. Furthermore, the approach to research in digitalisation is rather fragmented. In fact, the identified projects usually target each digitalisation technology individually. This fragmentation of research might well lead to creating/proposing solutions which will not necessarily grasp the full potential of digitalisation when put together.

### 1.8. Identified gaps in the digitalisation of the construction sector

The literature reviewed suggests two type of gaps; those specifically related to the construction sector and broader gaps related to the digitalisation concept. The latter contribute to discouraging industry investment in the digitalisation of the construction sector.

I. Gaps related to the construction sector include:

1. Limited obligatory digitalisation targets at the national levels which would encourage investment in the digitalisation of the sector.

2. Lack of investment in digitalisation technologies by the construction industry which might be due to the dominance of SMEs in the construction sector.

---

[57] The BUILDUP skills pillar II final evaluation report http://www.buildup.eu/en/news/build-skills-pillar-ii-final-evaluation-report-published

[58] https://cordis.europa.eu/projects/home_en.html

[59] EC (2013), Factsheet: Horizon 2020 budget. https://ec.europa.eu/research/horizon2020/pdf/press/fact_sheet_on_horizon2020_budget.pdf

3. Lack of trained employees on the use of digitalisation technologies which goes hand in hand with the lack of industry investment in digitalisation technologies and could also be due to the dominance of SMEs in the construction sector.

4. Lack of investment in research and development and more importantly a lack of a holistic vision for the research needs. Research projects identified in the CORDIS database are, mainly, focussed on the use of each single technology individually rather than on the combined use of the digitalisation technologies to grasp their full potential.

II. Gaps related to the broader digitalisation concept include:

1. Lack of software supporting standards, standardized tools, file types, methodologies, etc. which limit the possibility of collaboration between project stakeholders. The use of different software or tools make the communication more challenging and may discourage their use.

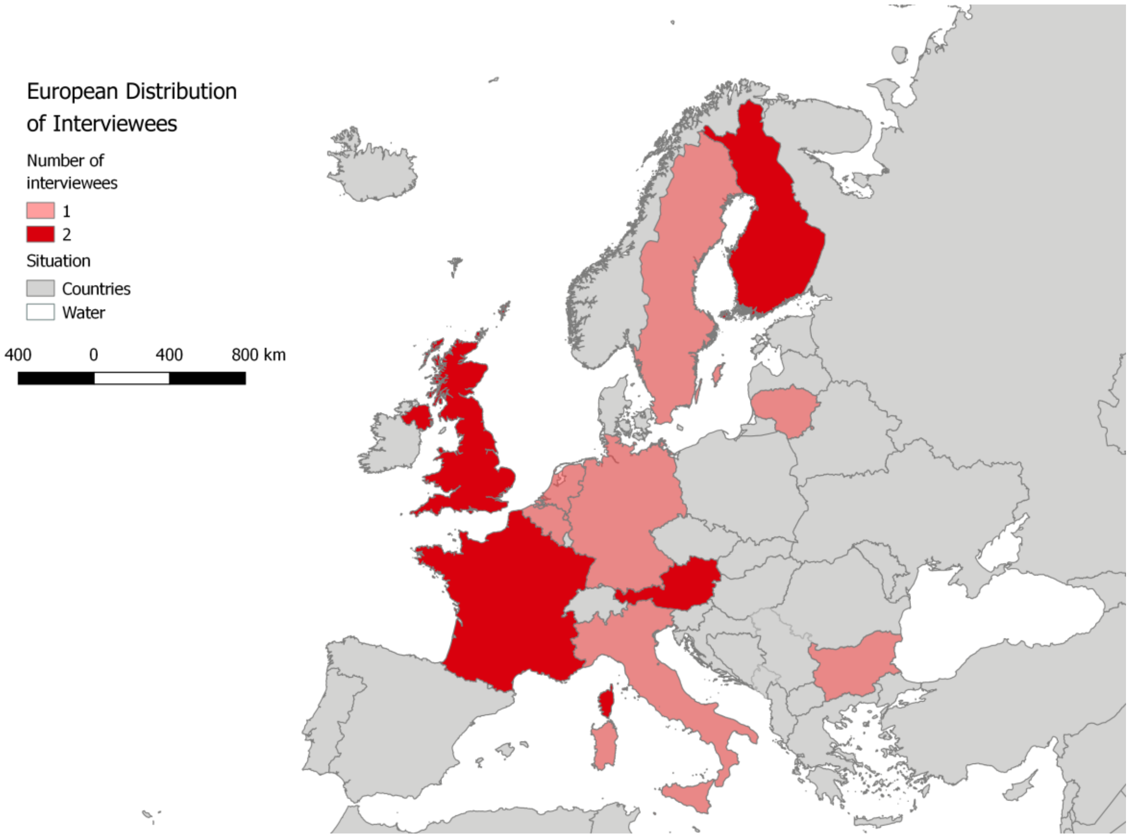
2. Lack of data security and preparedness for cyber-attacks: The extensive use of digitalisation tools will create an enormous amount of data that should be secured and made available to companies, for an effective use to optimise operations and performance. At the same time it should not be violating the ownership of private data rights. Data security is one of the prerequisites for accelerating the digitalisation.

# CHAPTER 2: EXPERT INTERVIEWS

## 2.1. Introduction

From the desk research we get an insight about the current state of digitalisation in the construction sector, including detected gaps as stated above. Next, the consortium conducted expert interviews with professionals and researchers working in the field. With the inclusion of interview comments as a preliminary step, we aim to confirm these findings on one hand, on the other we aim to go beyond by investigating more qualitatively about the current state of digitalisation with actual practitioners.
To do so, we elaborated a list of experts and representatives coming from research, academia, policy and industry, based on the discussions with the EC and the knowledge gained from the desk research in Chapter I. Finally, we were able to include 17 interview partners, coming from different backgrounds, including architecture/engineering (4), research (7) and IT specialists (6) from all over Europe as shown in Figure 4, including countries in Northern and Southern Europe. A full list of interviewees is attached in Annex D, including information about the Organisation, the type, the position within the organisations, the years of experience in the field and the country. While the number of interviewees is limited in this pre-step, it indicates the current state of digitalisation in the construction sector. A larger number of organisations will be contacted in a later stage. Next, we present the outcome of conducted interviews.

**Figure 4: European distribution of interviewees**



## 2.2. Interview findings according to Thematic Analysis

### Current Experience with Digitalisation

- *Experience*

  Our interview partners had different levels of experience with digital tools, approaching digitalisation in the hybrid construction sector from various angles, such as computing (five), engineering (six) or narrow construction (six). In doing so, they all have experienced the transition from paper drawings to CAD software and now for the last years have been introduced to 3D printing, laser scanning and BIM, which is increasingly becoming standard in their work. For most of our interview partners (seven out of 17) the use of BIM is the main technology where digitalisation has been introduced into their work. Others use or develop digital tools to pre-fill application forms for building permit, for instance, or use tools for augmented reality for construction.

  While interviewees working for larger companies have done the transition towards increasing digitalisation at least a decade ago, the majority of SMEs are currently within the transition phase facing some challenges, as this example shows: *"Since a year ago, we started operations in direction of BIM within the company. That made it very difficult to work in digitalisation, as there are different ways and standards even within the company. So, first step was to standardize the company, which means first of all moving files from the old environment to BIM 360, and get our Revit stuff working onto that platform."*

  This already shows a clear disadvantage due to size for companies and SMEs to adapt to digital tools for their daily business. In fact, four out of our 17 interviewees stated in their interviews that due to additional costs, time and pressure from customers SMEs have more difficulties to invest in research and development, including the adoption of digital methods.

- *Workflow benefits and drawbacks*

  **Benefits:** The use of digitalisation in their work offers an increase in time efficiency, especially for early design phases up to 50%, according to the experience of half of our interview partners.

  Five out of 17 partners stated that construction processes get streamlined and there is less risk due to quick assessment and an improved assembly management. This becomes clear for instance *"…if large changes have to be made during the design and construction process, where a parametric tool saves incredible amount of time."*

  In doing so, the use of tools and cloud services contributes to their work's reliability due to a steady information flow and increased interaction between the involved parties.

  **Drawbacks**: On the negative side, six out of 17 stated the communication among authorities, between authorities and companies and even international communication is problematic due to the lack of standards, as this example shows: *"Everybody is doing it on their own, they are not linked together; there is no harmony between UK, Nordic countries and France. Furthermore, there are totally different speeds in the development and investments at the moment."*

  Even in forerunner countries of digitalisation there are problems between different interfaces and regulations, as for instance in Finland even digitally developed 3D plans need to be submitted as 2D print-out plans to the building authority. Such processes lead to "*data destruction*", as one interview partner pointed out.

Another drawback that was identified by interviewees is the time-consuming management of BIM projects, which is becoming especially challenging to SMEs, compared to larger companies.

Additionally, three out of 17 interviewees mentioned the technical risks that might appear with an increased digitalized construction process, such as the creation of backup plans or combined services (link cloud and server, if the server brakes down…).

- *Effects of digitalisation on employment*

All interviewees agreed that digitalisation is and will continuously bring changes to job profiles in the construction sector. Three out of 17 mentioned that unskilled work will significantly decrease within the sector. Especially in the field of manufacturing, these interviewees see a high chance that current manual labour procedures will be transformed into an industrialized design processes and large-scale production, *"just as it has happened in the printing industry 30 years ago"*. In the opinion of these experts, drivers for this change are especially artificial intelligence and robotics. Nevertheless, two interviewees explicitly mention that they don´t use efficiency gained through digitalisation to lay off staff, but instead utilize the spare resources to increase the quality of their work for their clients.

In this context, it was also mentioned by one of the experts that digitalisation will empower the costumers, because they will be given the chance to take part in the design process. Regarding the work at the construction site, one expert predicts that a new job profile – the data preparator / data analysts[60] – will be established, who will solely be responsible to prepare daily bits of information for all hierarchy levels at the site. In this context, he also mentions that information structuring will be one key task in the digitalized construction sector of the future.

Four interviewees touch upon the issue of recruiting young ICT specialists which are digitally capable to implement and work with BIM. Their opinion is that, globally speaking, there is no lack of suitable people, but they are hard to get. In this context, the construction sector is competing with attractive employers such as the gaming industry. A shortage of qualified personnel in the Dutch IT sector is mentioned. Also, for Austria, it´s stated that BIM experts are *"very hard to get".* Especially for architects, the interviewees see a drastic change in the design process. Architects will be forced to engage with the new technologies and the design process will become even more integrative as it is today.

**Challenges**

- *Legal and technical challenges*

The majority (nine out of 17) of the interviewees stated that interoperability and missing standards are the biggest technical challenge that they are facing. One practitioner mentions that in his company, they are supporting more than 20 file formats. Even though some are acknowledging the open data format *IFC4add2*, they add that the export and import in software does not always work smoothly. Two

[60] Application of Big Data Analytics in Construction Industry, Forecast to 2022; Frost & Sullivan; August 2018: https://www.researchandmarkets.com/research/wbt94m/application_of?w=5

interviewees explicitly mention that they are programming their own APIs for their purposes.

Another issue that is raised by some of the interviewed practitioners (four out of 17) is the growing amount of data and the problem on how to deal with it. *"We invested a lot in our IT infrastructure, at a certain point, we changed to a cloud solution, when hardware became cheaper, everyone again got a laptop".* Especially for SMEs, the handling of large amounts of data and the introduction of new software leads to high costs. Therefore, it is not a surprise that two interviewees see the number of available software and apps as a challenge and they wish to decrease the amount of software which is being used in their company. Virtual & augmented reality is mentioned to be a key driver for the ever-growing data production in the BIM context.

- *Staff skill challenges*

Five interviewees explicitly mentioned architects as a profession that will have to undergo some major changes. Architects will have to adjust their skillset because they *"need to understand the entire design process digitally". "Computer programs can make thousands of drawings every night"* and *"form and function are optimized together"* giving architects the chance to concentrate on their key tasks and to finally get a much better end-design. In the literature, this is often referred as *"changing role of architects".* [61]

Also, interviewees see a growing need for team spirit amongst architects and other construction professionals as *"they need to work together in an integrative planning approach."*

Two interviewees mentioned that people have to be open minded and need the IT fundament, to be ready for the change that digitalisation brings. Employees need a *"willingness to learn and further develop the skills which are needed".* Another interviewee says that there is a *"lack of skills in many positioned firms who decide to use BIM. These people need to be trained and to constantly improve themselves".*

Three interviewees pointed out the need of modellers, BIM managers and *for "people who exploit the data"*, such as data analysts or scientists, also for educational purposes.

**Opinions on existing Initiatives**

- *Drivers & challenges of existing EU Initiatives*

**Positive:** Positive impacts, as mentioned by the interviewees, are the EU`s strength in creating good initiatives on European-wide and national level, as well as the financial support, especially in case of artificial intelligence which can further be used in planning and construction operations. For instance, the *"new compulsory BIM implementation for public construction contracts bigger than EUR 100 million, starting from 2019 – 2025"*[62] in the case of Italy is seen by four out of our 17 interviewees as a good starting point to unify workspace, and therefore reduce time for BIM training. Interviewees suggest that this could be expanded in a European-wide scale.

[61] http://www.future-architect.nl/en/

[62] https://ec.europa.eu/docsroom/documents/30665/attachments/1/translations/en/renditions/pdf

**Negative:** On the other side, large consortia of these projects have been criticized due to their inability of putting concrete things into action, as well as their increased duration to develop them.

In general, according to the interviews (?) EU standards are desired to enable comparability between the different approaches that individual technologies are currently implementing.

Generally, existing EU initiatives are perceived *as "positive steps into the right direction, even if the way is long*", by the interviewees. The inclusion of 28 individual nations, with all their diversity, is clearly seen as the major challenge such initiatives face. However, interviewees agreed that these initiatives will lead to an easier exchange of information, leading to adequate competitiveness among companies and competition for customers.

- *EU's expected Role*

The expected role of the EU is seen by nine of our 17 partners as a central platform of communication and standardization between all involved parties (from research to practise to legal) over all European countries. Such a platform should support and establish international standards, a funding scheme specifically dedicated to digitalisation and research and *"foster the collaboration between the countries, making specific cases where all the construction companies can cooperate within EU projects."* Thereby, current local differences within the European Union have been pointed out in terms of openness to technological innovations, as for instance between the European North (very tech-savvy) compared to the South (less tech-savvy).

**Boundary conditions**

- *Public awareness*

Being mostly business-to-business solutions, most of our interviewees rate public awareness of digital innovations in construction sector as rather low (nine out of 17), as the end-customers generally are not experts in construction and digitalisation sector and have barely insights into complex construction processes.

Nevertheless, five out of our 17 interviewees stated that due to an increase in publicity for smart technologies, especially in 'smart cities' – there is a rise in public awareness for digitalisation also when it comes to the built environment and the construction sector. Besides resulting novel opportunities, this process also leads to an increased pressure for businesses: *"The public awareness is getting better. Not because of the tools but because of publicly mentioned terms like smart tech, etc. Citizens are getting aware of terms such as ''energy efficiency'' and ''smart city'' and ''smart home''. This is putting pressure on the construction industry concerning BIM – they have to deliver a lot of data in real time, pushing the construction sector to build in better ways."*

Others point out the challenges for SMEs compared to large companies and are rather concerned about the digitalisation shift: *"There is awareness that BIM is coming. It´s challenging for a small company to start with BIM, it comes with a cost and the cost is very high. Large companies around them are starting with the digital shift, but what will happen if all the big companies have changed? Will the SME´s be able to follow?"* For them the main question arises on how to provide support for the small companies.

- *Legal guidance for digital innovations*

  A majority (ten out of 17 interviewees) are not satisfied with the current state of legal guidance for digital innovations (as for instance, with current standards and regulations), both on national or international level. The general opinion is that there has to be a combined EU-framework with local authorities, as *"there is no common understanding of where the construction industry has to go".* This includes, according to the interviewees, more guidelines and information (especially for the technical and legal aspects), standards, as there is no clear guidelines for BIM.

  As much as interviewees see the future with OpenBIM, there need to be guidelines installed first *("There is no dictionary for BIM that people can use - we need an EU definition for the BIM.")* to ensure conformity.

  Only interview partners from Scandinavian countries (Sweden and Finland in particular) are satisfied with guidance on national level, pointing out the necessity of cooperation between experts and politics, as this answer for instance shows: *"All workers on construction sites must have electronic worker control, this is regulated by law in Sweden and Finland. Companies are obliged to provide digital solutions to fulfil these requirements. Business self-regulation authorities have trust from political side (much more than elsewhere in Europe), this is much more difficult in European newcomers like Baltic countries. Politicians don't have understanding of digital processes, they can't be the ones guiding, it should be businesses and public sector working together to create the best solutions."* However, even though Scandinavia is one of the frontrunners in digital innovations for construction, there is still the necessity of physical plan drawings for legal processes, that must be improved according to one interview partner.

**Innovation possibilities**

- *Space for Experimentation*

  All our interview partners stated that they would welcome the opportunity to research and explore more for digitalization in construction. Three of them pointed out that they are steadily updating novel ideas for next steps of product development, in accordance to their customers which become an important driver for new inventions: *"Certainly! We have a long list of functionalities and ideas that are waiting to be implemented. By ourselves or in partnerships with other companies that provide additional functionalities to our product."*
  However, a majority (8 out of 17) of the interviewees would highly welcome an increase in EU programs offering them the necessary time and financial support to explore and implement novel digital technologies in their work. Such EU programs should be tailored to SMEs needs, while SMEs especially are dependent on such support.
  Besides EU programs, three of our interview partners see an increase of private investors as another chance to offering space for new innovations through R&D for their companies.

- *Research & Development investments*

  Generally, all our interview partners have stated, they clearly see a need in further investments in R&D for digitalization in the construction sector. Thereby they differentiated between three main sources, which are the investment from public funds, investments from private funds and internal investment from the company in their own R&D.

As research in this field is highly time-, resource- and cost demanding, especially SMEs and smaller companies face challenges who often cannot afford these costs. For instance, while four out of our 17 interviewees stated that they already invest internally into R&D to stay on the top of technological developments, five others said they cannot afford R&D development, if there is no external investment. Overall there is this notion that the larger the company, the easier it is to invest internally and hence, the less dependent one is from outer financial sources.

We further identified a preference especially for investments coming from the private sector, due to a less bureaucratic procedures and the loss of proposal writing (as stated by three interviewees). However, as one interview partner stated: *"We are not in the Silicon Valley, there are some chances to find investors – it's not so easy, compared to the US… people are a bit sceptical in investing."* This is in line with the fact that the amount of venture capital in the United States is six times higher compared to Europe.[63] This indicates that the EU does not attract enough venture capital. Therefore, it was announced in April 2018 that the European Commission initiated the VentureEU fund with 410 million Euro to attract other public and private investors.[64]

As observed by other interviewees, this is however slowly changing as clients become more aware of their own benefits due to digitalisation: *"…historically it was very hard to take innovative approaches, clients were not ready, but clients got huge benefits out of it … and get away from the traditional approach"*.

- *Staff skills*

Generally, interview partners are very supportive for staff to develop new skill sets related to the digital evolution in the business, weather through in-house staff training or training courses outside the company, as for instance at universities.

Four out of 17 interview partners coming from engineering and computing stated clearly that technical capabilities, programming and coding is needed more and more to keep pace and to provide latest technology.

However, half of our interviewees pointed out, that construction business is including a very wide field of different professions including actors with different background and skills, from construction to IT people and that not everybody needs to know coding for instance.

'Soft skills', as for instance, leadership, teamwork, collaboration, analytical thinking and problem solving, are even more important to them for the increasing digitalisation in construction than technical skills itself. At the same time, these skills cannot be taught through conventional learning processes. Therefore, a general opinion of our interviewees was that a shift in education is needed, as one example shows *"I think education has challenges to face - not so much about technical skills , but about soft skills, such as collaboration, problem solving."*

This indicates that digitalisation brings up a necessity of different roles and responsibilities (more "tech" knowledge as referred to here as coders). These roles can be picked up by existing players in the value chain(such as an architect who is familiar with coding) or ones that are not embedded to the traditional roles in the

[63] https://www.europa-nu.nl/id/vknef7f8rrzv/nieuws/eu_programma_moet_durfkapitaal?ctx=vh6ukzb3nnt0

[64] https://www.hln.be/geld/economie/eu-zet-in-op-durfkapitaal-zodat-innovatieve-ondernemers-niet-langer-wegtrekken-naar-vs~aa155501/

construction, such as IT manager, Knowledge Manager, BIM manager, BIM modeller etc.

- *New digital platforms*

  All of our interview partners would support a new and extended digital platform, even though more than half pointed out that there are already a number of platforms currently running, such as Bimserver.org *("…my proposal is, let's do the audit of the existing systems, not invest millions in a new one. French, Italian and British already have one – so we could find out, which one to take…"*).

  Four of our participants favoured a platform supporting public – private partnership.

  In this sense, a new platform should include several novel features that have not been implemented but are missing. In doing so, they should enable international usage, while being able to take local regulations into account. One participant mentioned, that an installation of an EU body that understands and controls standards and regulations would be helpful for that matter. Another feature would be the incorporation of cloud services and open data, enabling the usage on a broader level.

### 2.3. Summary & Conclusions from Interviews

In summary, results from our interviews underline clearly several challenges detected already in Chapter I, emphasizing the importance of taking-action. More precisely, these are:

- **Lack of 'soft skills',** such as leadership or teamwork, that are not being taught in university courses, and the need of staff between different professions (such as data science and design). Furthermore, with the increasing amount of data due to digitalisation there is specific need for data managers for data handling purposes.

- **Lack of investments,** to support and enable R&D for digitalization in the construction sector. Three main sources have been identified: 1. the investment from *public funds*, 2. investments from *private funds* and 3. *internal investment* from the company in their own R&D department. Within these sources, the importance of *private investment* and the *tailoring of public investment* have been pointed out especially for SMEs, as they are most dependent on such financing schemes.

- **Lack of standardised software and data exchange formats**, leading to issues in communication between authorities, between authorities and companies and even international communication/information exchange, as export and import in software often does not work smoothly. This leads to work-arounds by individual companies by developing their own 'standards' (such as building their own API's for instance) and hence, increasing this problem. Blockchain technology has been suggested as a possible solution to standardise and facilitate communication on large scale. There is also a **lack of software (both open source and commercial off-the-shelf) that uses the available asset lifecycle information management standards.**

- **Lack of standards and guidance for the technical and legal aspects of digitalisation**, making it difficult to communicate on national and international level – especially in the context of open data and open BIM.

Besides communication issues, this furthermore leads to major differences in adaptation within the EU, from the more-developed European North (Scandinavian countries in particular), to the South. Also here, Blockchain technology has been suggested as a possible solution to facilitate EU guidance on large scale. A **lack of complementing asset life-cycle information (ALIM) standards** was also mentioned by the experts.

Besides emphasizing known issues, the results of the interviews outlined additional gaps that must be included in further discussions:

- The EU is seen as facilitator and, rather than a support for practical implementations of digitalization in the construction sector. **The interviewees also mentioned that the EU is a necessary actor to deal with market failure and a lack of cooperation on a Member States level**.

- **Data handling and analysis**: The increasing and rapidly growing amount of data modern technology in construction (as for instance increasing augmented and virtual reality applications) works with, becomes a problem in terms of data management, handling and management.
  Based on the large variety of modern technologies, this leads besides its management and handling to the necessity of analysts that are able to make sense out of it by developing and implementing data analysis and statistical methods.

- **Barriers resulting from differences in company size:** As R&D is very time consuming and expensive, most of our interview partners have stated the clear disadvantage of SMEs at almost every stage above mentioned – from implementation of digitalization in their daily workflow, to technical difficulties, such as software and data management, to disadvantages in evaluation processes.

Looking at these findings (summarized in Table ES 1), we see that half of our found gaps have been identified in both, in the desk research and the interviews (five out of 10). We interpret these results as an indicator for the necessity of taking-action by the European Commission.

We further detected three new gaps that have not been identified by the literature and prior studies, which are in particular: 1. The lack of practical implications by the EU, 2. Lack of experts for data handing and analysis and 3. the lack of standards. Overseen by past studies as described in Chapter 2, we now detect in this study their impact, challenging practitioners and stakeholders. For future research outside of this study, our findings open doors to shed more light into these topics.

Having identified gaps from the desk research (Chapter I) and refined and extended them in a series of expert interviews (Chapter II), in our next report we will be able to suggest a list of actions to the European Commission (Chapter III).

Based on the consortium’s prior work, we will outline first a list of prior elaborated 10 actions that will be refined according to our findings from Chapter I and II. We will then assess selected actions and deliver an action proposal, including 2-4 actions. Results will be presented in Chapter 3 and 4.

Chapter V will include a recommendation for a roll-out plan of these 2-4 actions within the next 3 years after completion of the current study.

# CHAPTER 3: GAPS AND PRELIMINARY ACTIONS

## 3.1 Objectives and Scope

This chapter describes the actions proposed to digitalise the construction sector by building upon the findings from chapter 1 and 2, that identified a list of gaps through in-depth literature reviews and expert interviews.

In doing so, it follows three steps for selecting the actions to be proposed to the European Commission for financial support needed for the implementation:

- Within the **first step**, actions were suggested for each of the identified gaps. The proposed actions were cross-checked with existing EU initiatives to avoid overlaps and to ensure complementarity. Furthermore, for each proposed action, a preliminary feasibility assessment was made.
- Within the **second step**, the proposed actions were grouped by categories whenever relevant.
- Within the **third step**, two to four actions were selected for further investigation on the possibility of financial support by the European Commission.

The selection process was conducted based on discussions and feedback from the European Commission and other relevant stakeholders from the industry. The latter was done through bilateral consultations and a webinar, hosted on the 16th of January 2019, involving various umbrella organisations in the construction sector (see Annex E for detailed information about consulted organisations). The selected actions were further developed, elaborated, and validated in terms of their viability towards the development of a roll-out plan in Chapter 5.

Based on our findings from chapter 1 and 2, we identified 10 existing gaps the construction industry faces with its digitalisation (Annex A). These gaps can be summarized in four categories:

- **Baseline & monitoring:** this concerns the current situation including the lack of digitalisation targets at EU and national levels, and limited capabilities of SMEs for digitalisation and limited R&D in the construction sector. The situation needs to be monitored over time to see if these gaps become smaller. There are existing monitors like the Digital Transformation monitor of the EU. [65]

- **Technical & financial measures:** this includes the lack of investment in the implementation of digital technologies by the construction industry. Furthermore, a lack of investment in R&D by SMEs (especially for the integration of digital technologies), market failure, and a lack of cooperation between the public and private sectors to accelerate the digital transformation are among the existing gaps.

- **Skills & human resources:** this concerns a lack of trained employees on the use of digital technologies and a lack of experts for data handling and analysis.

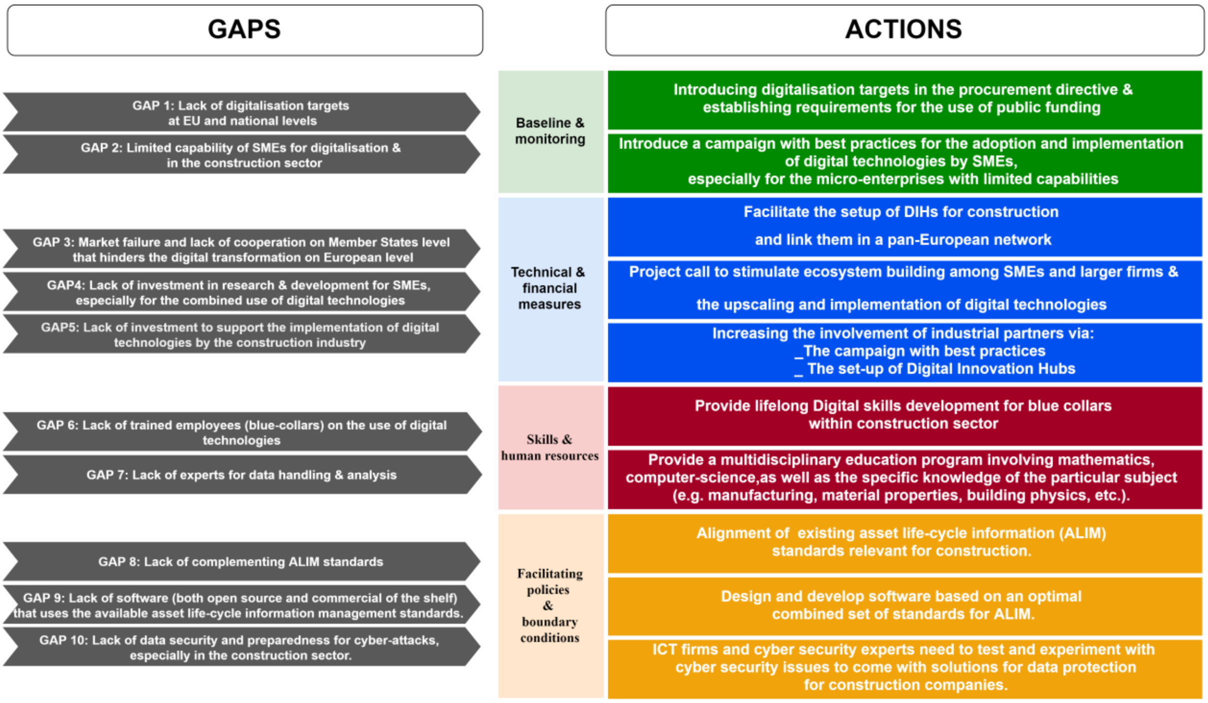
- **Facilitating policies & boundary conditions:** this includes a lack of complementing Asselt Lifecycle Information Management (ALIM) standards and a lack of software (both open source and commercial off-the-shelf) that uses the

[65] https://www.google.com/search?q=digital+monitor+european+commission&ie=&oe

available ALIM standards. Furthermore, there is a lack of data security and preparedness for cyber-attacks.

To be able to bridge each of the identified gaps we propose 10 actions (Figure 5). Hereafter we describe how each of the proposed actions will bridge the identified gaps.

**Figure 5 : Identified Gaps and their corresponding Actions**




- **<u>Identified gap 1: Digitalisation targets are lacking at EU and national levels</u>**

From a policy perspective, the EU Directive (2014/24/EU) on public procurement is the only policy instrument which refers to the use of digitalisation technologies in the construction sector. The revised Energy Performance of Buildings Directive (2018/844/EU) introduced new provisions to promote smart systems and digital solutions, including building automation and electronic monitoring of technical building system as a means to achieve energy savings (in a cost-efficient manner). Building Information Modelling (BIM) is the only digitalisation technology mentioned in the directive. Next to that, the transposition of the directive at national level varies greatly across Member States, with only eight Member States having made the use of BIM mandatory in public procurement (Austria, Denmark, Finland, Germany, Italy, Luxembourg, Spain and the UK). The UK adopted such a requirement for the use of BIM in public projects prior to the adoption of the 2014 EU Directive on procurement and is now leading the use of BIM for different construction projects. BIM remains the only digitalisation technology required on a mandatory basis for public works and design in the aforementioned Member States.

**Action:** The introduction of digitalisation targets in the EU procurement directive and establishing requirements in the use of public funding can help to accelerate digitalisation in the construction sector. In practice this would mean that the use of digital tools is encouraged for public procurement i.e. public works / design contests. These targets should be SMART (Specific, Measurable, Attainable, Relevant, Timely). To help shape these targets, the Commission could launch public online consultation specifically targeting relevant stakeholders. The challenge lies in fact that the construction sector internationally is one of the least digitised industries (as it has been pointed out by McKinsey[66] and is repeatedly stressed by the EU BIM Task Group, composed by public clients and policy makers[67]). Digitalisation targets put forward at an EU level would encourage Member States to transpose such targets and requirements to national legislation. This would effectively encourage the uptake of digital tools – including, but not limited to, BIM - by construction industry companies operating across EU Member States with such requirements. As pointed out earlier in the report, seizing the full potential of the digitalisation of the construction sector requires combining BIM with other digitalisation technologies such as automated fabrication, robots, 3D printing and scanning, drones, sensors and the Internet of Things (IoT).

- **Identified gap 2: Limited capability of SMEs[68] for digitalisation in the construction sector**

Budget and schedule overruns due to unforeseen modifications are the norms in the construction sector, especially wherever a design is to be tailor-made, e.g. for renovation projects. Often, the executives of SMEs are aware that digitalisation can improve their overall business efficiency. However, there is a need for guidance and instruction in assisting executives of SMEs in taking their first steps toward digitalisation. In spite of the urgency[69] of digitising the construction sector (in the context of the overall digital revolution), the majority of traditional construction actors on the ground, (ex. SMEs such as contractors, and sub-contractors including masons, carpenters, ironworkers, plumbers, or electricians) often do not have the capability to digitise their businesses quickly enough to catch up with the speed of technological advancements, let alone innovating in the digital realm. This lack of capability is due to several factors such as difficulty of envisioning the potential digitised futures of their business, low digital maturity-level of the employees and the employers, and most importantly, the inherently limited human-resources. For brevity, we refer to all these matters as 'limited capability'. Furthermore, in most business specific areas, it is not easy for the SMEs to pinpoint what the essential/relevant digital skills are.

**Action:** We propose a framework implemented in an existing digital platform for construction (e.g. Digital Platform for Construction in Europe, DigiPLACE, DT-ICT-13-2019[70]), consisting of the following components:

1) Questionnaires for self-assessment of digital maturity levels in business-specific areas,

2) Interactive handbook which allows the integration of current and future instructions and strategies to improve or reach a certain digital maturity level within specific business areas,

3) Promoting best-practices,

4) An open Q&A forum to facilitate the interaction between SMEs,

The aim of this action is to help executives of SMEs overcome their inertia towards the digital transformation. To this end, they need to understand at what digital maturity level

66 McKinsey (2016) Digital europe:pushing the frontier, capturing the benefits - McKinsey

67 Recent example: Euractive (2019) Construction: The least digitised sector in Europe

68 For example, architects, specialists/advisors and the many small contractors and subcontractors

69 Digitalization of the Construction Industry: The Revolution is underway, Oliver Wyman

70 https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/dt-ict-13-2019

they are (with the help of digital maturity scan) and how to improve their digital maturity level (with the help of an interactive handbook). It is envisaged that the European Commission, in this action, plays the role of a facilitator and supervisor by providing funding resources (e.g. in the form of service contracts) through launching a call for development of the proposed self-assessment tool and interactive handbook. Moreover, during the course of the project, The European Commission can coordinate Europe-wide support activities (EU exchange meeting(s) for community of practices in the field of digitization). This should support the exchange of best practices at an EU level and stimulate the interaction between communities of practitioners to share knowledge about the current digital maturity level within specific business areas and specific digital skill needs and shortages. The outcome of these meetings will guide further development of the proposed action.

- **Identified gap 3: Market failure on the European construction market and lack of cooperation at Member States level that hinders the digital transformation on a European level.**

Chapters 1 and 2 of this project indicates that there is market failure on the European construction market and a lack of cooperation at Member State level in accelerating the digital transformation in the European construction sector. Market failure means that there is a limited amount of R&D investment by construction firms for digitalisation although it is known that investments in R&D&I to digitalise the construction sector contribute to knowledge spill-overs[71] and productivity.[72] The lack of cooperation on Member States level relates to the fact that firms (often SMEs) in construction have a strong focus on a specific lifecycle stage/phase and supply-chain level resulting in a lack of cooperation between these firms to develop and combine digital technologies.

**Action:** Digital Innovations Hubs (DIHs) for construction technologies are needed to solve this market failure and stimulate cooperation between firms and other relevant partners in the construction sector (e.g. knowledge institutes, education institutes and the government). DIHs also need to be aligned in a pan-European network to join forces on European level and give the opportunity to strengthen each other and learn from each other.

*"A **Digital Innovation Hub (DIH)** can be defined as a support facility that helps companies become more competitive by improving their business processes as well as products and services by means of digital technology. DIHs act as a one-stop-shop, serving companies within their local region and beyond, to digitalize. They help customers address their challenges in a business-focused way and with a common service model, offering services that would not be readily accessible elsewhere. The services available through a DIH enable any business to access the latest knowledge, expertise and technology via the technology infrastructure (competence center) for testing and experimenting with digital innovations relevant to its products, processes or business models. DIHs also provide connections with investors, facilitate access to financing for digital transformations, help connect users and suppliers of digital innovations across the value chain, and foster synergies between digital and other key enabling technologies (such as manufacturing technologies, advanced materials, etc.)".*[73] (see Figure 6)

---

[71] https://publications.tno.nl/publication/34623736/CHnLkb/TNO-2016-R11435.pdf
[72] JRC, 2015 (Energy renovation: The trump Card for the New Start for Europe).
[73] http://publications.tno.nl/publication/34625485/D5Io8n/TNO-2017-R10967.pdf.

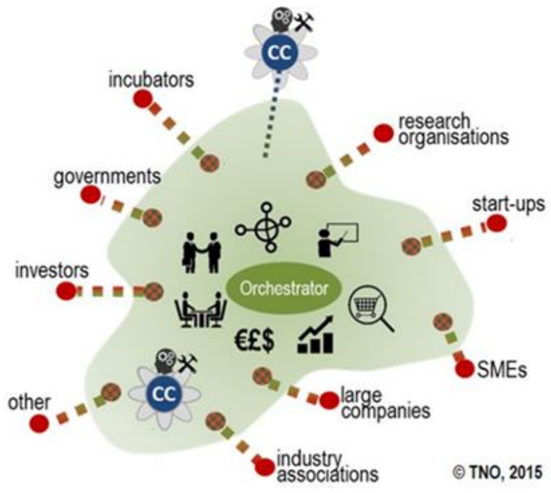



**Figure 6: Digital Innovation Hub with the involved stakeholders (e.g. SMEs, research organisations, large companies, competence center (cc) etc.)**[74]

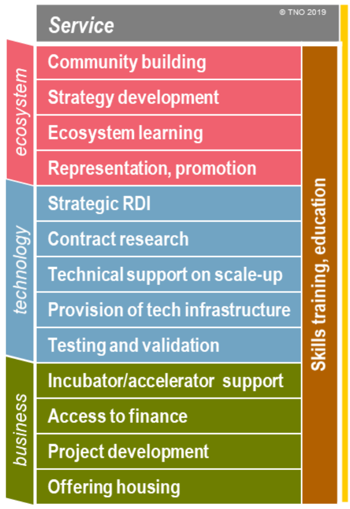



**Figure 7: Services offered by DIHs (TNO, 2019)**

Table 2 indicates how DIHs address market failure. [75, 76] The services available through a DIH are presented in Figure 7.

**Table 2: How DIHs address market failure**

| | |
|---|---|
| | **How digital innovations hubs (DIHs) address market failure** [77, 78] |
| **Positive externalities and knowledge spill-overs** | *"DIHs encourage knowledge spill-over through joint projects, networking and training"*<br><br>*"DIHs work on innovations which are beneficial to society at large, but cannot be sufficiently appropriated by individual firms"*<br><br>*"DIHs work on innovations that are ahead of the market"* |
| **Imperfect and asymmetric information**: | *"DIHs help companies to assess and reduce uncertainties"*<br>*"DIHs create awareness"* |
| ***Coordination and network failures*** | *"DIHs bring actors together and facilitate cooperation"*<br><br>Linking DIHs in a pan-European stimulates cooperation between the different Member States. |

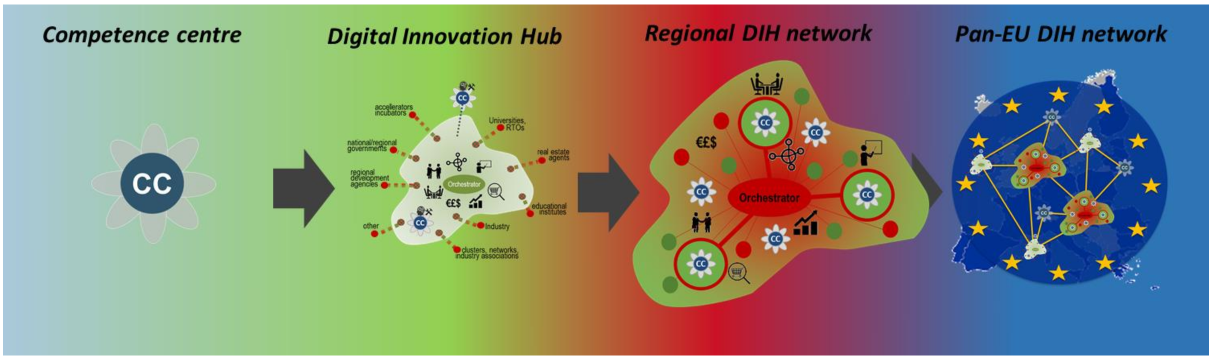
[74] http://s3platform.jrc.ec.europa.eu/digital-innovation-hubs
[75] https://publications.tno.nl/publication/34623736/CHnLkb/TNO-2016-R11435.pdf.
[76] In report from 2016 we are referring to DIHs are called field labs
[77] https://publications.tno.nl/publication/34623736/CHnLkb/TNO-2016-R11435.pdf
[78] http://ec.europa.eu/competition/state_aid/modernisation/rdi_framework_en.pdf

**We suggest the European Commission to facilitate the setup of DIHs for construction and their pan-European cooperation via two complementary calls:**

- DIHs are well known in other sectors, but not in construction (except for some exceptions[79]). That means the stakeholders (e.g. small and larger firms) in the construction sector do not have experience with DIHs. Therefore, **we suggest that funds are provided to Research and Technology Organisations (RTOs) and/or consultants who can coach new DIHs for construction** and give advice to the stakeholders from the DIHs in the regions (e.g. CEO of the DIH and his or her assistant) on how to organise their DIHs. More details about the coaching of DIHs will be discussed in Chapter 4.

- Cooperation among different EU regions can be encouraged by providing funding for a call for development and upscaling of digital technologies for construction by consortia of DIHs from different Member States. **Such a call should lead to the creation of a pan-European Network of DIHs to support the construction sector** (see Figure 8 below). This pan-European network will furthermore stimulate the knowledge transfer between the regions and give SMEs access to expertise that they do not have in their own region. More details about the role of the European Commission in this action will be described in Chapter 3.

**Figure 8: From a DIH to a pan-European DIH network (© TNO, 2019)**




- **<u>Identified gap 4: Lack of investment in research and development for SMEs, especially for the combined use of digital technologies.</u>**

Overall, more than 90% of construction companies are SMEs,[80] each having a strong focus on a specific lifecycle stage/phase and supply-chain level. The advantage of this situation is that these firms are all experts in different steps of the value chain and construction process. However, the landscape of SMEs in the construction sector is fragmented and consists of companies that have difficulties accessing finance for R&D. This leads to a slow adoption and combination of digital technologies by SMEs, their adherence to traditional business models, and often to inefficiency in operations (due to communication and hand-over problems, for instance).

---

[79] Like Thermoplastic composites NL, smart housing DIH in Thessaloniki GR and 3DMakerzone http://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool5

[80] For example, architects, consultants, engineers, Quantity Surveyors, Schedulers & Estimators, Contractors, Sub-Contractors, Building System/Component/Material Suppliers/Manufacturers, Construction ICT Software Vendors, Technology Providers

**Action**: We suggest to create ecosystems that contain SMEs and large companies in construction that work together on experimenting, testing, implementing, and combining digital technologies (e.g. digital twins, robotics, BIM etc.), to help overcome the aforementioned fragmentation.[81] This cooperation also helps to share costs and technological knowledge. Large companies profit from the highly specific expertise that SMEs have in a very specialised topic and that the l large firms do not have themselves. This contributes to improved supply chain cooperation, which will improve services for the consumer.
Such ecosystems need to be initiated in the regions of the Member States with the support of regional development organisations. To stimulate these ecosystems and hence to accelerate the upscaling, implementation, and combination of digital technologies that require more attention, the European Commission can play a facilitating role. This can happen via project funding,[82] for which the European Commission can stimulate the formulation of digitalisation targets that ecosystem partners (e.g. SMEs and large firms) should fulfill when applying for the project funding. These targets relate to the type of technology the ecosystem needs to work on.

- **Identified gap 5: Lack of investment to support the implementation of digital technologies by the construction industry.**

A major challenge for SMEs, as detected in chapters 1 and 2, is to bridge the gap between research and implementation of digital tools and methods in the construction sector (e.g. BIM, Robotics). This is often due to a lack of investment by firms in the sector.

**Action:** We suggest bridging this gap via two actions. To stimulate the investments in the implementation of digital technologies by industrial partners, it is necessary to show the added value of using digital technologies. Therefore, we introduce in the action 2 (see Figure 1) an interactive handbook and a digital maturity scan with best practices and practical steps to firms to digitalise Digital Innovation Hubs (DIHs) could later help SMEs to solve their (non-) technical challenges (e.g. giving advice on the financing of innovation and business models related to their digital innovations). Furthermore, it will provide insights into the added value of the digital technologies (e.g. proof of concepts can be presented), to stimulate the private investments of construction firms in digital technologies.

- **Identified Gap 6: Lack of trained employees (blue-collars) on the use of digital technologies**

2016’s skills forecast by CEDEFOP suggests that employment in construction will grow during 2015-2025 and Member States will need to replace an ageing workforce. Around one million new workers will be needed by 2025. Skill requirements are likely to change also to meet the demand for green buildings.[83] A digital transformation will be essential in delivering more efficient buildings. Demand for skilled labour has increased but the number of jobs for those with lower-level qualifications has shrunk. Promoting lifelong training is crucial to reduce the gap between the supply and demand of digital skills.

**Action:** In order to address digital skill shortages and to respond to the current and emerging digital skills needs of the construction sector, a set of training and development

[81] Each of the SMEs have a strong focus on a specific life-cycle stage/phase and supply-chain level

[82] https://ec.europa.eu/growth/access-to-finance_en

[83] 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. http://ec.europa.eu/social/BlobServlet?docId=19499&langId=en, http://www.buildup.eu/en/skills

programs should be developed and implemented. This will contribute to an increased number of qualified workers, skilled in the use of digital technologies, across Europe. To achieve this goal, the New Skills Agenda for Europe has already launched the Blueprint for Sectoral Cooperation on Skills initiative for construction sector. The Blueprint for the Construction Industry brings together three EU umbrella sectorial organizations, along with 9 national sectorial representatives and 12 Vocational and Education Training providers (24 partners) from 12 EU Member States. Their goal is to develop a new sectorial strategic approach to cooperate on skills development in the construction industry and support a better matching between skill needs of companies and skills provided by training centers.[84] In synergy with this existing initiative, we propose an action which aims to improve the dissemination and utilization of the developed training materials in the Blueprint via their inclusion in an interactive handbook. This can be facilitated by the European Commission through launching a service contract related type of funding mechanism for education experts (with expertise in the construction sector and digital technologies) so that they can implement the relevant trainings in an "interactive handbook" (which is a result of the action related to gap 2, see Figure 1) for employees in the construction sector.

- **Identified Gap 7: Lack of experts for data handling and analysis**

Chapters 1 and 2 indicated that there is a lack of data scientists and experts with expertise in (big) data handling and analysis in the construction sector. More specifically, experts capable of utilizing spatial data for improving time/budget efficiency in the construction sector are scarce. Spatial Data is used either in analysis and decision-making or synthesis and design in construction sector. The types of expertise required for utilizing data is different in each case, though there are some common skills required in both areas.

1. Synthesis and design: being able to utilize spatial data, such as BIM models, point-clouds, parametric models, CAD models and alike is especially important in tailor-made projects such as renovations, e.g. for speeding-up modifications, foreseeing and estimating the number of required fittings, and even automatically generating assembly instructions. Such application areas demand deep practical knowledge of both design and construction, as well as data models (information content and its structure in different file formats, database schemas), algorithms and eventually the mathematics (geometry in particular) related to the task.
2. Analysis and decision-making scenarios:
    - Utilization of IoT sensor-data together with user-generated data, consumption data, or infrared-picture data for finding the determinants of energy-inefficiency and making corresponding decisions for improving energy efficiency,
    - Utilization of drone-collected data for monitoring safety on a construction site.

   Such scenarios also often require computational (algorithms & data-models related), and mathematical (geometry, statistics, and machine-learning) knowledge and skills.

**Action:** Advancing the utilization of spatial data in the construction sector requires a skill-set particularly involving mathematics, computer-science, as well as the specific knowledge of the particular subject (e.g. manufacturing, material properties, building physics, etc.). These are technical skills that are typically scarce within the current pull of practitioners within the construction sector. In addition, due to the inter-disciplinary nature of the problems, it is not easy to hire external experts outside of the construction sector to solve problems. To overcome this shortage of experts for data handling, new experts need to be

[84] http://www.sckr.si/tsc/mic/projekti/erasmus-plus/61-projekti/erasmus-plus/skills-blueprint-for-the-construction-industry-allcon/165-skills-blueprint-for-the-construction-industry-allcon.html

educated. To this end, new courses which contain both methodological skills (mathematics, computation, building-physics, manufacturing, structural mechanics, etc.) and technological skills (programming languages, software applications, and alike) need to be integrated in the curriculum of higher education for construction disciplines. The target groups of this action are mainly students who will attend the courses. Higher education of the Member States will have an important role to the implement this action.

- **Identified gap 8: Lack of complementing Asset Lifecycle information Management (ALIM) standards.**

Chapters 1 and 2 showed that ALIM standards for the construction sector are not aligned. A harmonized set of standards is needed to create the required interoperability (i.e. so that systems can communicate with each other).

**Action:** To close this gap, European and global standards for ALIM need to be aligned. The relevant set of international and European standards for a given context should be clear so that (standards) developers are aware of potential interactions. Next to that, each standard under development should indicate how it relates to the other (final or in development) standards. Finally, new higher-level harmonisation efforts (manual or via supporting tools) could help to control this process of alignment. A standard (knowledge) 'system' for interactions between standards as framework could facilitate this process too.

ISO TC59/SC13/WG8 'Information Container for Data Delivery (ICDD)' DIS was for instance rescoped to more easily combine it with standards in CEN TC442 WG4 which on their turn can now be nationally extended in national standardization like in NEN (the Netherlands). This was successful because there happened to be overlap in people between these groups feeling the need for alignment. In general, such alignment should be analysed, planned and organized.

The following stakeholders need to do this in cooperation:
- Standardisation bodies (like ISO, CEN, W3C, bSI, OMG) that define the relevant, generic or domain-specific, data standards for the construction industry.
- Firms in the construction sector (demand and supply side) that apply the standards. The needed alignment should be driven by their business requirements and interfaces.
- Software suppliers bringing in their capabilities to implement and handle the standards (i.e. without the support of software suppliers there will be no standards usage).

Key ALIM standardisation topics that need alignment are Building Information Modelling (BIM), Geo-spatial Information Systems (GIS), Systems Engineering (SE), Monitoring & Control (M&C) and Linked Data / Semantic Web (LD /SW). A detailed list of these topics is presented in Annex H. Standards should be simple enough to be used. This is especially true for SMEs (e.g. architects, specialists/advisors and the many small contractors and subcontractors) that have no experts on underlying technologies.

- **Identified gap 9: Lack of software (both open source and commercial off-the-shelf) that uses the available asset life-cycle information management standards.**

There is a lack of software that uses/supports the currently available ALIM standards. This is caused by fragmentation (e.g. everyone is using their own standards) and a lack of critical mass for using any specific standard. The lack of harmonised standards leads to a lack of interoperability (i.e. systems that cannot communicate with each other).

**Action:** To close this gap, software vendors/developers need to design and develop software based on an optimal combined set of standards for ALIM. Firms in the construction sector (demand and supply side) need to apply the software based on these standards.

- **<u>Identified gap 10: Lack of data security and preparedness for cyber-attacks, especially in the construction sector.</u>**

Chapters 1 and 2 indicated that construction firms lack data security solutions and are not prepared for cyberattacks.

**Action:** To close this gap, ICT firms and cybersecurity experts need to study and understand cybersecurity issues to come up with solutions for data protection for construction companies. DIHs would be a good environment to bring together the cybersecurity and ICT experts and construction firms for proper cyber studies and tests (see the action linked to gap 3). Therefore, we suggest cybersecurity as one of the priority topics to be covered by the DIHs.

# CHAPTER 4: PROPOSED ACTIONS FOR THE EUROPEAN COMMISSION

## 4.1 Methodology and criteria for selection of the proposed actions

In the scope of this study, two to four of the proposed actions out of 10 should be prioritised. The selection process of the two to four actions has been done based on the following criteria:

A. **The prioritised actions are proposed to be facilitated by the European Commission:** This criterion therefore excludes actions that require a facilitating role of the Member States or mainly rely on the leadership by the industry, and standardisation bodies.

B. **Impact:** The prioritised actions should have a clear influence on the digitalisation. of SMEs. Therefore, actions dedicated to the digitalisation of SMEs in terms of digital skills development and testing, experimenting, and implementation of digital technologies are prioritised.

C. **Feasibility of the implementation** of the proposed actions:[85]
   The feasibility check on the proposed actions included the following indicators:
   1. *Timing*
   2. *Budget*
   3. *Synergies/Overlap* with existing initiatives were identified via the following activities:
      - Investigating the existing initiatives for synergy, improvement and collaboration;
      - Interviewing the **E**uropean **C**onstruction, built environment and energy efficient building **T**echnology **P**latform (ECTP)[86] representatives;
      - Investigating funding opportunities;
      - Organizing a webinar with stakeholders from umbrella organisations (a list of contacted organisations can be found in Annex J);
      - Consultations of representatives of the European Commission and the construction industry.

**Based on the aforementioned selection criteria, three actions are recommended and require a facilitating role of the European Commission:**

i. Introduction of an interactive handbook and a digital maturity scan for the adoption and implementation of digital technologies
ii. Facilitation of the setup of DIHs that could help the construction sector digitalise and link them in a pan-European network
iii. Provide lifelong (Digital) skills development for (blue collars) within the construction sector

Next, we present the content of the prioritised actions, including the results of the feasibility check of the selected three actions (Section 4.2).

---

[85] As mentioned on page 11 in the inception report a feasibility study has been conducted for 2-4 actions.

[86] http://www.ectp.org/about-us/

### 4.2 Selection and feasibility check of the proposed actions

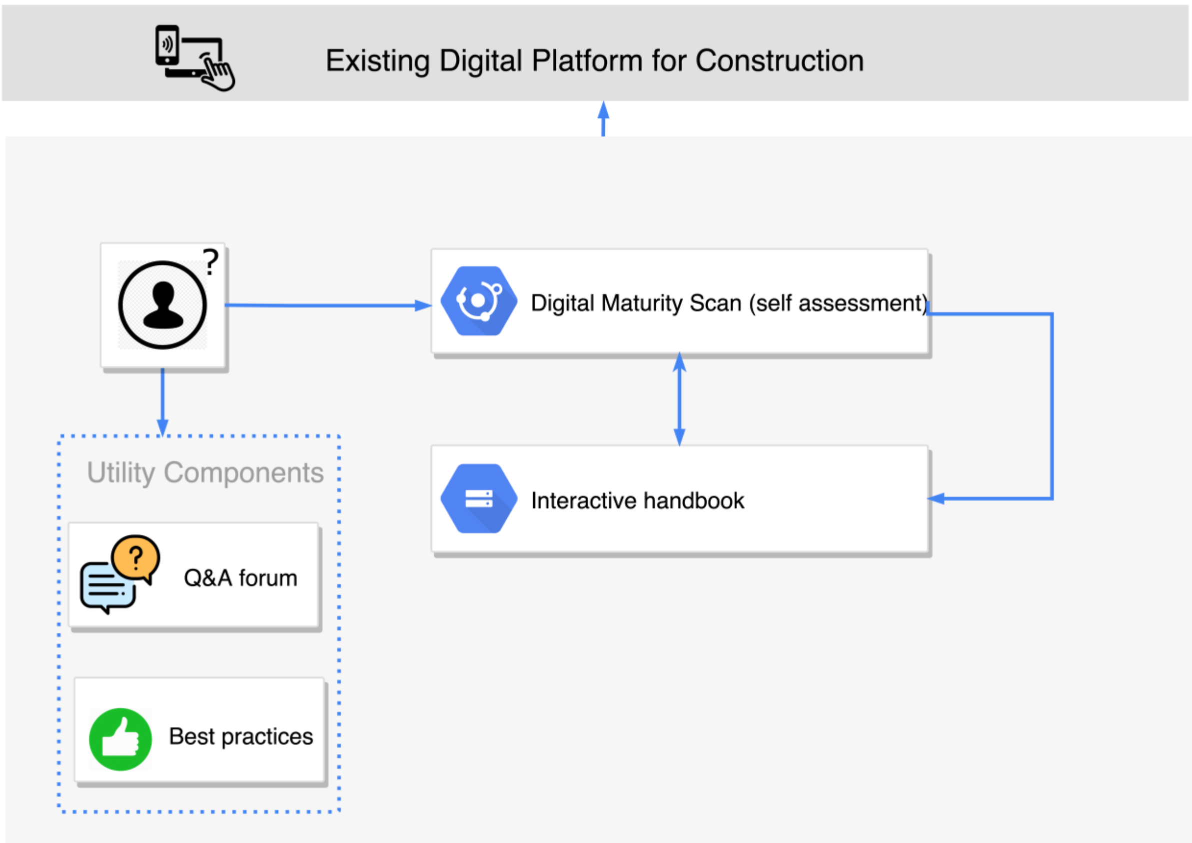
Based on the prioritisation process as described above, two of the proposed actions **are complementary to existing initiatives in the construction sector** (Action I and Action III), which are concerned with the best practices for SMEs and the (Digital) skills development. One action concerns **a for the construction sector complete new initiative** (Action II) to facilitate the setup of DIHs for construction and link them in a pan-European network.

**Action I: Interactive handbook and digital maturity scan for the adoption and implementation of digital technologies**

**Challenge:** The challenge is to increase the adoption of digital technologies by SMEs, especially the microenterprises with limited capability, by providing guidelines and instructions embedded in an existing digital platform.

Action: This action aims to devise a framework to assess the digital maturity level of SMEs and to setup an interactive digital handbook which allows the integration of current and future training materials to reach a certain level of digital maturity. The digital maturity scan tool will measure the current digital maturity level of the SMEs and the interactive handbook will help them improve their digital maturity level. The tool and the interactive handbook would be made operational on an existing digital platform (see Figure 9).

**Figure 9: The suggested components to be implemented in an existing platform**



As shown in the Figure 9, four main components are suggested to be implemented in an existing digital platform for construction:

1) Self-assessment of digital maturity levels,

2) Interactive handbook which allows the integration of current and future instructions and strategies to improve and reach a certain digital maturity level within specific business areas,

3) Match-making service, promoting best-practices,

4) Question and Answer forum,

The above-mentioned components can be implemented in an existing digital platform for construction. Such a platform can help the managers of SMEs leveling up the digital maturity of their organization by providing a maturity scan tool and an interactive handbook containing training materials. A forum of question and answer will facilitate the interaction between SMEs by sharing their experiences and knowledge and ultimately will generate a sense of community among the participants. SMEs can implicitly promote their firm by answering questions on the forum and learn from the others by asking questions, up-voting helpful answers, and following guidelines or instructions. This will allow the platform to stay alive while all participating SMEs gradually improve their maturity level interacting with each-other and following the given handbook.

In summary, the following activities are required to be performed within this proposed action. More detailed information about these activities can be found in the roll-out plan.

- A consistent, unified, and agreed understanding of "different digital maturity levels" across different business specific areas need to be defined. This will be the base to measure the digital maturity levels of SMEs. [Unified scaling]
- Online questionnaires need to be devised in order to determine SMEs' digital maturity/readiness level for digitalisation. [Self-Assessment]
- Suitable structure needs to be defined for the interactive handbook.
- Collaboration with other value chain players needs to be promoted (in synergy with Action II) in order to share resources. This will help SMEs to adopt and implement the recommended guidelines. [Implementation]
- Inspiring examples of SMEs who have successfully adopted digital technologies in their work-flow will be collected and promoted.

**Action II: Facilitate the setup of DIHs to support the construction sector and link them in a pan-European network**

**Challenge:** With this action, we want to bridge the market failure gap and the lack of cooperation on a Member State level that hinders the digital transformation as described in Chapter 2.

**Action:** We proposed two interrelated calls in Chapter 2 that are described in more detail in this section:

- **Coaching programme for new DIHs for construction**. **R**esearch and **T**echnology **O**rganisations (RTOs) and/or consultancy organisations with experience in the setup of DIHs in other sectors would provide a mentoring and coaching program for stakeholders that want to set up or recently set up a DIH for construction technologies. The aim of the mentoring program is to give advice about how to setup and or organise a DIH (the program contains for instance advice on funding innovations, organisation structure, IP etc.) and to give the DIHs the chance to exchange knowledge and meet each other during the coaching sessions. It is important that this coaching program is put in place. There are more than 400 DIHs in the EU, but only a few DIHs for construction.[87,88] That means that DIHs for the construction sector or DIHs providing digital technologies useful for construction needs to be stimulated. The facilitating role of the European Commission assures that the selection of DIH initiatives participating in the coaching program takes place in a transparent way.

- **Creation of a pan-European network of DIHs from the various regions and countries that cooperate on the development and upscaling of digital technologies for construction.** Via this pan-European network, companies can access competences and facilities not available in the DIH of their region. This network will lead to knowledge transfer between regions and will be the basis for economies of scale and investments in the DIHs. We recommend making a link with the existing pan-European network of DIHs.

Within the pan-European cooperation on development and upscaling of digital technologies DIHs should focus on one or more of the following **topics:**[89]

  - Maintenance/renovation of existing construction assets (particularly in the context of energy transition) and newly created assets.
  - Assets from both buildings (residential & utility buildings) & infrastructure (roads, bridges, tunnels).
  - Clear material/energy-efficient (sustainable), positive end-user impact on safety, health, work satisfaction etc.
  - Preference to holistic/integral approaches covering the total lifecycle and supply-chain of construction assets.
  - Not only traditional construction processes but also more industrial prefab-oriented, mass-customized building involving parametric solutions of product development.
  - Digital Transformation & Interoperability via shared knowledge/data spaces & libraries based on agreed and unified open standards.
  - Next-generation deploying technology (3D scanning/printing, construction robotics and Artificial Intelligence (AI) including Machine Learning (ML) all executed in a high-performance computing environment and digital connectivity (e.g. Digital Twins) via 5G roll-out.
  - Cyber Security & Trust (like Privacy, Authentication, Authorisation and Blockchain).

[87] Like Thermoplastic composites NL, smart housing DIH in Thessaloniki GR and 3DMakerzone http://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool5

[88] Various experts confirmed that there are currently no DIHs directly related to construction but only a few ones addressing indirectly the sector (e.g. robotics, 3D printing, Thermoplastic composites[88]). The Digital Innovation Hub catalogue of the Smart Specialisation Platform[88] provides an overview of DIHs in Europe. When selecting the sector "construction" within this database 179 DIHs appear that cover technologies like Robotics or 3D printing that might be relevant for construction, but also for other sectors like manufacturing or health. However, this database does not include DIHs specifically dedicated to the construction sector except for some exceptions as mentioned in the previous footnote. Stakeholders that are willing to setup a DIH for construction are recommended to contact existing DIHs that develop technologies that are relevant for construction to see if they can cooperate and to avoid that the new DIHs will reinvent the wheel.

[89] These topics are based on the stakeholder consultation during the feasibility study.

- The setup of a virtual data space (like FIWARE[90] or the International Data Space (IDS)[91]) in which partners in business ecosystems can securely exchange and easily link their data. The main goal of the digital platform is to facilitate the exchange of data between data providers and data users in the construction value chain. DTICT13 will work on this, but a follow-up could be covered by a pan-European network of DIHs.

**Action III: Provide lifelong (Digital) skill development for (blue collars) within the construction sector**

**Challenge**: The challenge is to increase the number of skilled workers, especially on-site workers, in the use of digital technologies.

**Action:** In order to find synergies with current initiatives and to avoid repeating similar actions, existing initiatives (as indicated in Annex J) have been studied. Our proposed action 'Life-long digital skills development for blue collar workers within the construction sector' is building up on current initiatives, in particular "Skills Blueprint for the Construction Industry". The Blueprint will be starting its deployment by getting main market players involved (Education, Business, Government, Society) in taking up opportunities to make the best of their talents. Within the scope of the Skills Blueprint for the Construction Industry, the following activities will be performed[92]:

1. *To collect good practices at a national and regional level to illustrate and promote other initiatives addressing skill gaps.*
2. *To design and deliver a Massive Open Online Course (MOOC) to start upgrading workers' skills in digitalisation and to raise awareness among construction workers about new skill drivers: digitalisation, energy efficiency, and circular economy.*
3. *To create the tool WatchTower to provide valuable information about particular skill needs at least at regional/national level.*
4. *To build upon a revision methodology of construction professional profiles and qualifications.*
5. *To carry out an outreach campaign to promote its attractiveness among younger individuals and women, identifying and promoting solutions to facilitate the mobility of construction workers in Europe.*
6. *To create a new virtual tool (SSA Portal) where all project outputs will be available for stakeholders, as well as a Sector Skills Alliance platform for collaborative work.*

Our proposed action is geared towards improving the dissemination, classification and utilization of the training materials which have been already collected by other initiatives such as "Skills Blueprint for the Construction Industry" or will be recognized and delivered. This will be achieved by implementing and utilizing the up-to-date training materials in a digital handbook and training workshops through synergy with our proposed Action I (Interactive handbook and digital maturity scan for the adoption and implementation of digital technologies). In other words, within our proposed Action I, the structure (framework) of an interactive handbook will be defined and developed (based on the

---

[90] https://www.fiware.org/about-us/

[91] https://www.internationaldataspaces.org/our-approach/#about-us

[92] https://ec.europa.eu/programmes/erasmus-plus/projects/eplus-project-details/#project/600885-EPP-1-2018-1-ES-EPPKA2-SSA-B

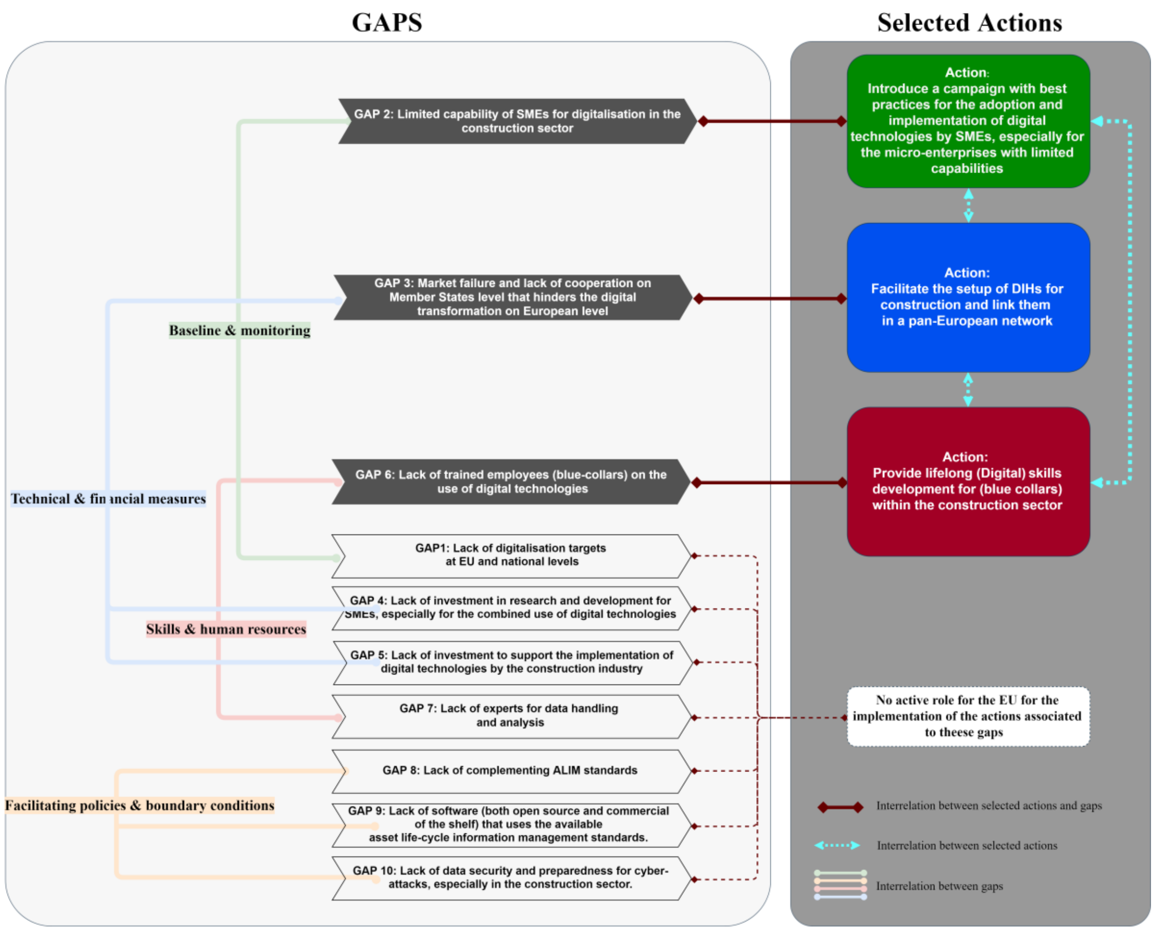
identified areas for digital improvement for each targeted business-specific area in order to reach a certain level of maturity) and within proposed Action III, suitable and up-to-date guidelines, instructions, and training materials (to achieve a certain level of digital maturity) will be selected and implemented in the interactive handbook. This will make the training materials exploitable by consolidating the relevant training materials (gathered from relevant initiatives such as Blueprint) in one digital handbook. More detailed information about the recommended tasks can be found in the roll-out plan.

### 4.3 Conclusions related to the proposed actions

Responding to the 10 gaps for digitalisation in construction, as described chapters 1 and 2, this report defines 10 actions that will support the development and application of digitalisation in the construction sector. These actions suggest activities such as digital skills development, stimulating R&D, accelerating the combination and implementation of digital technologies, harmonising national digitalisation initiatives and cooperation between the quadruple helix partners (industry, governments, research and education institutes) (e.g. via DIHs and their pan-European network).

Three of the 10 actions could be facilitated by the European Commission in cooperation with the industry and other stakeholders. Seven of the 10 actions could be mainly executed by the industry and other players rather than the European Commission. A check that followed the selection of the three actions by the European Commission concludes that these selected actions are feasible. The overview of the selected actions is presented in Figure 10.

**Figure 10:Overview of selected Actions, and possible relationships between them (indicated by arrows)**



# CHAPTER 5: ROLL OUT PLAN

This chapter concerns the roll out plan of actions to support the digitalisation of the construction sector and to help SMEs develop as part of the contract 'Supporting digitalisation of the construction sector and SMEs including Building Information Modelling (BIM)'.

The roll out plan refers to the three actions that were selected in chapter 3 and 4 after carrying out an analysis of potential actions to tackle current gaps in the digitalisation of the construction sector and SMEs therein. The three actions to roll out are:

(1) Action I: Introduce an interactive handbook and a digital maturity scan for the adoption and implementation of digital technologies

(2) Action II: Facilitate the setup of Digital Innovation Hubs for construction and link them in a pan-European network

(3) Action III: Provide lifelong (digital) skill development for (blue-collar workers) within the construction sector

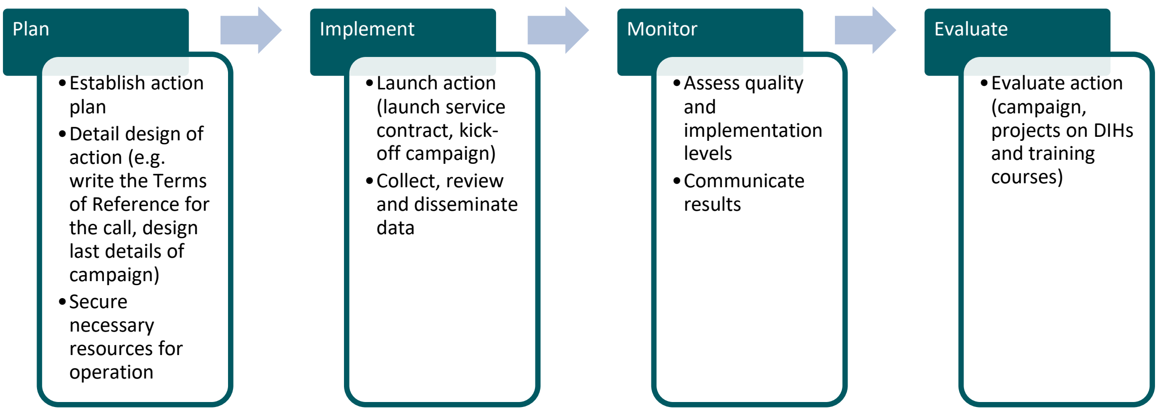
The three proposed actions have undergone and passed a feasibility check according to the criteria of timing, budget and compatibility/synergies with ongoing efforts (explained in chapter 3 and 4).

The aim of the roll out plan is to propose a course of action for the Commission to be able to implement such actions. For all three actions this will involve the Commission launching a call for proposals. The roll out plan provides both technical as well as organisational suggestions for implementing the actions and includes the following sections:

- Background / context for each action;
- Tasks and responsibilities to be outlined in the call for proposals for each action;
- Indicative time schedule for each action;
- Indicative budget allocation for each action;
- Anticipated risks and necessary mitigation measures.

The following chapters explain the course of action for the roll-out of the actions. The focus of this roll out plan is mainly in the 'planning' stage. However, to the extent possible the key elements to be taken into account at the different stages are addressed. A snapshot of what each phase of the policy cycle will address is illustrated in Figure 13 below to give an indication of the steps that will follow the planning stage.

**Figure 11 : Phases in rolling out each action according to the policy cycle stages**



## 5.1 Recommended roll-out for action I: Interactive handbook and digital maturity scan for the adoption and implementation of digital technologies

### 5.1.1 Background and context

The construction sector consists of several specialized fields of work, each of which varies in terms of targeted market segment, employment size, and their contribution to the construction sector. Each field of specialization within this broad sector could benefit from different digital skills. For example, the digital skills required for surveyors are different from those required for carpenters, plumbers or BIM modellers and computational designers. SMEs, by definition, due to their small size and limited scope along the value chain, are not likely to have a full picture of digital possibilities or the concrete steps they can take to digitize their business. It is therefore difficult for an SME to determine the extent to which their organization is digitised and what the areas for improvement could be. Moreover, digital technologies pertinent to the construction sector are currently undergoing rapid developments and small and medium sized organizations cannot easily dedicate enough (human) resources in keeping up with all developments. These challenges hinder SMEs to take the first steps towards digitalization and consequently induce inertia towards digital transformation. In order to empower decision makers and tech-savvy influencers within SMEs steering towards digitization of their businesses, it is essential to provide a coherent and big picture of potential digital strategies for 'business-specific' areas. Furthermore, due to rapid developments in the digital domain, continuous skills development and training are very crucial to keep up with the technological development. Due to this long-term and resource intensive investments, a sustainable digitalisation strategy must be well reflected on within the context of technical services or specific engineering of the concerned SMEs. Most importantly, however, an SME must plan for learning about the potentials of digitization and improving their proficiency levels in the areas pertinent to their business by continuous learning and developing their skills. In order to define a learning strategy, SMEs need to:

1. Understand where they stand in terms of digital maturity
2. Identify their objectives and the way of accomplishing them (how to increase their digital maturity level)

Therefore, the aim of this action is to help SMEs increase the digital maturity of their organization by providing a maturity scan tool and an interactive handbook. More specifically, the digital maturity tool is aimed to identify the current level of maturity and the interactive handbook is aimed to assist the managers of SMEs identifying the relevant training materials for their employees to reach a certain level of maturity.

### 5.1.2 Rationale and purpose

The objective of the proposed action is to help SMEs finding a learning strategy to gain relevant digital skills. To this end, they need to understand their current digital maturity level (with the help of digital maturity scans) and identify their objectives and the way of accomplishing them (with the help of an interactive handbook).

### 5.1.3 Requirements

To successfully implement the proposed action, it is suggested to carry out the following tasks:

- **Task 1:** <u>Benchmark and define a unified scaling for the digital maturity of SMES for business specific areas.</u> In order to define benchmarks, best practices for different business specific areas need to be identified, documented, and introduced; not only in terms of facts and figures but also in terms of concrete digital methods that need to be verifiable and practically repeatable. The contractor will be required to define a consistent method of measuring digital maturity based on qualitative and quantitative measures related to the impact of digitalization in terms of increased efficiency or effectiveness (such as cost savings, productivity, environmental impact, etc.). Naturally, different business specific areas will require different bases for their metrics of digital maturity, but eventually they need to be all comparable with each other[93]. Moreover, the contractor should identify the areas for improvement (for each targeted business-specific area) which are relevant and required in order to move up to the next level of digital maturity. In summary the following activities are required to be performed:

1. Identifying of best practices for each business-specific area;

2. Identifying different levels of digital maturity and the corresponding relevant qualifications for each level;

3. Identifying the areas for improvement in order to level up and reach the next level of maturity.

The outcome of this task will be used as a basis to develop the digital maturity assessment tool and interactive handbook.

- **Task 2:** Develop an online questionnaire for self-assessment of digital maturity level for each identified business-specific area (Digital maturity assessment tool). A digital maturity calculator could be developed which would assess and find out where an SME stands in terms of digital skills and how they compare with their industry peers in terms of digital maturity. The assessment tool should provide a set of criteria to evaluate the digital maturity level in business-specific areas. The set of questions should be based on the unified scaling identified in task 1. The questionnaires should be mainly formulated toward the managers and executives (someone who directs the training and performance of the organization and has a good overview of the digital skill levels of their employees and make decisions on strategy and other key policy issues).

- **Task 3:** Set up an interactive digital handbook. The principles which form the structure of this handbook should be based on the identified areas for digital improvement for each targeted business-specific area (identified in task 1) to reach a certain level of maturity. This template will allow the integration of relevant training materials which are essential to reach a certain level of maturity. The sections of the handbook should make up a coherent whole and at the same time, each section should be designed to stand alone (be self-contained and self-explanatory) by reiterating the key introductory concepts, and thus can be published separately.

- **Task 4:** Set up a forum to facilitate the interaction between SMEs. Proposals are expected to devise a framework to support the interaction between SMEs to share their experience and learn from each other in the journey of digitizing their organization. One possible idea is to set up a Q&A forum to facilitate the interaction between SMEs.

- **Task 5:** Perform an inventory of existing and ongoing digital platforms. Proposals are expected to implement the interactive handbook, the digital maturity scan and the forum in an existing digital platform. Various platform development activities exist at an EU level and there are relevant ongoing initiatives at EU level to initiate

[93] For instance, a level B in Digital Skills for MEP (mechanical electrical plumbing), a level B in Digital Skills for Surveying and a level B in Digital Skills for Woodworking should be comparable at least in terms of similarity of technical depth.

a digital platform (e.g. Digital Platform for Construction in Europe, DT-ICT-13-2019[2]). To ensure a successful implementation, a feasibility study needs to be performed at an early stage of the project to identify the required IT architecture to implement the components on an existing platform.

### 5.1.4 Define indicative period and duration of roll-out

In order to have an effective connection with the on-going initiative related to the digital platform (e.g. Digital Platform for Construction in Europe, DT-ICT-13-2019[94]), it is recommended to launch a call for the development of an interactive handbook and maturity scan tool as soon as possible. It is therefore, recommended that contract is signed approximately in the first quarter of 2020 for a period of 12 months.

### 5.1.5 Intended contributors and participants of the roll-out

In order to have a comprehensive understanding and an agreement about the different digital maturity levels and required digital training materials for SMEs, the contractor needs to involve the relevant experts and needs to initiate an industry collaboration. To this end, the bidding consortia should include a strong mix of organisations for example:

- **Higher education** and/or research institution to give insight and recommendation about the state of the art and offered digital courses;
- **Vocational and educational training institutions** to give insight about job-specific technical training;
- **ICT experts** to identify the required IT structure for the implementation of the proposed components in an existing platform;
- **National sectorial representatives** to give insight about the digital skill mismatches at national level.

## 5.2 Recommended roll-out for action II: Facilitate the setup of DIHs for construction and link them in a pan-European network

### 5.2.1 Background and context

Digital Innovation Hubs (DIHs) support companies and in particular SMEs in their digital transformation and help SMEs to solve their (non-) technical challenges (e.g. giving advice on the financing of innovation and business models). (see Figure 12). The objective of this action is to facilitate the use of DIHs in construction via the following to actions:

1. To coach new DIHs for construction by Research and Technology Organisations (RTOs) or consultants from the EU Member States and,

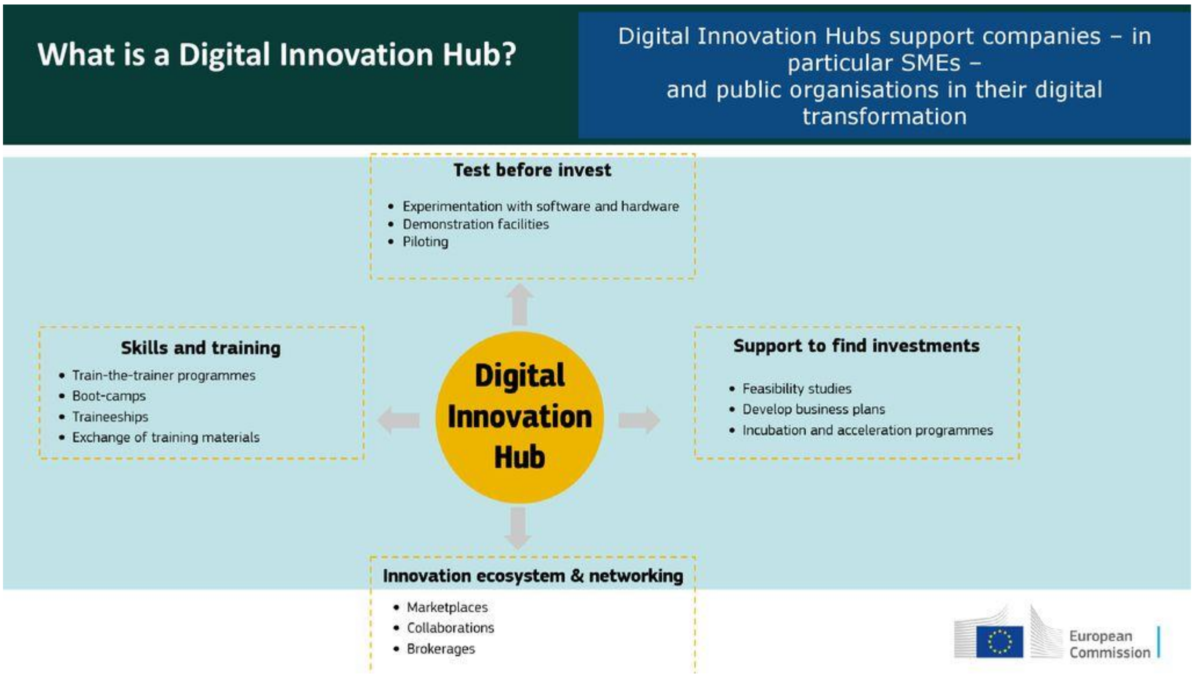
2. Create consortia of DIHs from different EU Member States that work on the development and upscaling of digital technologies.

Successful implementation of these activities can set the basis for ensuring the long-term competitiveness of the construction sector in EU Member States and for Europe as a whole. This action will build on achievements and lessons learned from previous and ongoing relevant initiatives such as ICT Innovation for Manufacturing SMEs (I4MS), which has already completed a mentoring programme for 29 new DIHs in various sectors.[95]

---

[94] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/dt-ict-13-2019
[95] https://ec.europa.eu/digital-single-market/en/blogposts/boosting-digital-innovation-hubs-across-europe-filling-white-spots

**Figure 12: The role of DIHs to accelerate the digital transformation of the construction sector**




### 5.2.2 Rationale and purpose

These two aforementioned actions (the coaching of DIHs and the pan-European cooperation between DIHs for the development and upscaling of digital technologies) contribute to the efforts to build a network in the European construction sector where companies - especially SMEs - can have access to expertise, development and testing facilities of digital technologies, as well as innovation and services:

1. The first action aims to provide the coaching to new DIHs for construction on how to organise their DIH. During this coaching programme the new DIHs have the chance to meet each other during the coaching sessions and exchange knowledge and expertise. This will contribute to their pan-European network cooperation.

2. The second action aims to stimulate DIHs to cooperate on the development and upscaling of digital technologies to stimulate the knowledge transfer between the regions and to provide SMEs access to expertise that they do not have in their own region.

Being part of the network of DIHs via these two actions, each DIH could improve its capabilities to support business innovation, by strengthening its cooperation with other DIHs and by learning how to integrate cooperation in its business model.

### 5.2.3 Requirements (definition of tasks)

The coaching programme provided by the RTOs and/or consultants will include different types of coaching activities like the development of a business plan, insights in funding options, skills development, marketing and communication to promote the DIHs etc. The coaching will be divided into thematic modules. Every coaching programme will include components applicable horizontally and more tailored topics. The goal is to provide potential DIHs with business development skills and help them for instance with their feasibility study and business model definition.

The RTOs and or consultancy firms will carry out the following **tasks** with the selected regional Digital Innovation Hubs[96, 97]:

- **Task 1:** Announce online via one of the webpages of the European Commission that a coaching programme will be provided to which new DIHs in the European construction sector can enrol themselves to participate in the coaching programme. This coaching programme is relevant for the CEO of the DIH and his or her assistant. This will give them the possibility to coach their colleagues (e.g. firms and SMEs involved in the DIHs) afterwards based on the 'train the trainer' principle. The DIHs need to motivate why they want to participate in the coaching programme when they enrol via the website. A Steering Committee is suggested to be set up to supervise this initiative. It will be composed of five experts from government, academia, industry, associations etc. This steering committee will be involved in the selection of the most relevant DIHs. This selection is suggested to be done in cooperation with the European Commission.

- **Task 2:** Provide a methodology with appropriate selection criteria to select the most appropriate DIHs for the coaching programme.

- **Task 3:** Explain the type of services that the DIH in I4MS or SAE have developed to help SMEs and mid-caps with their digital transformation, and which ones would be useful for the companies in the construction sector;

- **Task 4:** Provide coaching about business development skills, in order to identify local firms and SMEs that need help with their digitalisation, managing opportunities, providing a professional service, promoting the regional Digital Innovation Hub model of continuous cooperation between industry, academia, Research and Technology Organisations (RTOs) and the government; The coaching programme will be designed according to the needs of selected DIHs as much as possible.

- **Task 5:** Provide coaching on how to build a sustainable activity, which includes identification of regional and national funding opportunities with a special focus on the regional Research and Innovation Strategy for Smart Specialisation (RIS3) and the European Fund for Strategic Investment (EFSI), explaining costs and charging models and the value of a multi-funding approach.

**Call for the development and upscaling of digital technologies[98, 99]**
The objective of the call is to stimulate the development and upscaling of digital technologies including the pan-European network cooperation within the construction sector. Two types of innovation **tasks** are suggested to be conducted by a consortium of DIHs from different Member States. Via these DIHs various SMEs can be involved in these tasks:

1. **Application Experiments** to bring together all actors of the construction value chain and experts necessary to equip new SMEs with novel products or services and assist them in customising and applying these in their respective environments.
2. **In Equipment Assessment Experiments**, suppliers of innovative high-tech equipment (e.g. 3d printers and scanners robotics) install and assess their prototypes in construction-like environments and validate them. Activities are expected to be clustered in larger projects to achieve critical mass through the added value that pan-European cooperation can offer. Common tasks include: targeted dissemination about digital solutions; management of calls for new development and upscaling actions; exploitation of synergies across development and upscaling actions. The action may involve financial support to third parties. The

[96] The suggestion of these tasks are based on previous calls like I4MS.
[97] Tender specification DIH network 2017 https://infoeuropa.eurocid.pt/files/database/000078001-000079000/000078163_2.pdf
[98] The text is inspired by a comparable call https://cordis.europa.eu/project/rcn/198773/factsheet/en
[99] See https://cordis.europa.eu/programme/rcn/665048/en

consortium will define the selection process of additional users and suppliers running the experiments for which financial support will be granted (typically in the order of € 50.000 – 150.000 per party). A maximum 50% of the EU funding could be allocated to this purpose.

### 5.2.4 Indicative period and duration of roll-out[100]

To execute and prepare the coaching program 12 months are needed. To execute the development and upscaling of digital technologies by the DIHs between 3 and 5 years are needed.

### 5.2.5 Intended contributors and participants of the roll-out

The participants of the coaching programme are CEOs of the DIHs and his or her assistants.

The consortia of DIHs that will work on development and upscaling of digital technologies consist for instance of a consortium of about 4 DIHs including in SMEs and the mid-caps involved in these 4 DIHs.

The DIHs involved in both of the aforementioned activities should address one or more of the following **topics by request:**[101]

- Maintenance/renovation of existing construction assets (particularly in the context of energy transition) and newly created assets.
- Assets from both buildings (residential & utility buildings) & infrastructure (roads, bridges, tunnels).
- Clear material/energy-efficient (sustainable), positive end-user impact on safety, health, work satisfaction etc.
- Preference to holistic/integral approaches covering the total life-cycle and supply-chain of construction assets.
- Not only traditional construction processes but also more industrial prefab-oriented, mass-customized building involving parametric solutions of product development.
- Digital Transformation & Interoperability via shared knowledge/data spaces & libraries based on agreed and unified open standards.
- Next-generation deploying technology (3D scanning/printing, construction robotics and Artificial Intelligence (AI) including Machine Learning (ML) all executed in a high-performance computing environment and digital connectivity (e.g. Digital Twins) via 5G roll-out.
- Cyber Security & Trust (like Privacy, Authentication, Authorisation and Blockchain).
- The setup of a virtual data space (like FIWARE[102] or the International Data Space (IDS)[103]) in which partners in business ecosystems can securely exchange and easily link their data. The main goal of the digital platform is to facilitate the exchange of data between data providers and data users in the construction value chain. DTICT13 will work on this, but a follow-up could be covered by a pan-European network of DIHs.

## 5.3 Recommended roll-out for action III: Provide lifelong (Digital) skill development (for blue-collar workers) within the construction sector

[100] Based on experiences with existing calls within I4MS
[101] These topics are based on the stakeholder consultation during the feasibility study.
[102] https://www.fiware.org/about-us/
[103] https://www.internationaldataspaces.org/our-approach/#about-us

### 5.3.1 Background and context

Digital disruption is changing every industry including construction. These changes occur when new digital technologies and business models affect the value proposition of existing service providers. Skilled labour force (blue collar workers) is currently one of the main drivers for the construction industry. According to the 2016 skills forecast by CEDEFOP, employment in construction will grow during 2015-2025. Due to the digital transformation, skill requirements are likely to change to meet the demand for skilled labourers. In the context of rapidly evolving digital technologies, one cannot merely rely on previously learnt skills (e.g. in a vocational degree program) to excel in a digitally disrupted business. In this context, promoting lifelong training is crucial to reduce the gap between the supply and demand of digital skills. The reason this action targets the blue collars within the construction sector is that they are the human resources that can practically utilize digital technologies during construction. The educational qualifications (vocational degrees) of technicians have a practical approach to engineering directed at utilization of methods, components, techniques, tools, and systems. Therefore, in principle, technicians have an apt utilitarian basis for gearing digital technologies to work for increasing efficiency and effectiveness in the construction sector. The purpose of this action is to boost the momentum of practical education in the field of construction for adopting digital technologies by broadening the scope of vocational training from degree programs to life-long learning. The training programme must be aimed to equip the employees with relevant digital skills or digital crafts in their specific field of work within construction sector (e.g. for masons, carpenters, ironworkers, plumbers, or electricians).

### 5.3.2 Rationale and purpose

The objective of the proposed action is to increase the number of skilled workers, especially on-site workers, in the use of digital technologies Requirements.

### 5.3.3 Requirements (definition of tasks)

To successfully implement the proposed action, it is suggested to carry out the following tasks:

- **Task 1:** Identifying business specific areas within the construction sector who are the least digitized and recognizing their particular (digital) skill needs

- **Task 2:** <u>Define the practice-oriented syllabi containing a list of the challenges, instructions, and assignments for the identified domain-specific areas in task 1</u> (e.g. for masonry, carpentry, etc.) and demonstrate both the practical relevance and theoretical soundness of the training syllabus, and its relation to the outcomes of the following activities:
    - Action I which will identify the areas of improvement to reach a certain level of maturity for each targeted business-specific area
    - action II which will provide facilities and tools for training purposes
    - 'Skills Blueprint for the Construction Industry' which will identify the digital gaps and required training courses to minimize the gap of supply and demand of digital skills

  In addition, the contractor should propose and justify (in the documentation) effective forms of training (hands-on training courses: a face-to face and physical interaction with tool and/or online training courses) for each targeted specialization (e.g. for masonry, carpentry, etc.). The results of Task 1 must be implemented in the interactive handbook developed in Action 1.

- **Task 3:** <u>Conducting two rounds of training workshops to train the trainers with a minimum of 15 participants (technicians or supervisors of blue collar workers) focusing on practical construction challenges to be tackled using digital technologies</u>. The framework of the workshops should be devised based on the methods and syllabi developed in the task 2. The aim of these workshops is to increase the number of skilled supervisors who can train on-site workers on the use and implementation of digital technologies relevant to their field of work. The targeted participants are worker supervisors who will learn how to run training sessions. The workshops should include detailed presentation of different demo cases where participants can test and try-out digital technologies. Anonymized feedback from workshop participants must be collected, documented, analysed, and reflected upon to improve and verify the effectiveness of the proposed training courses. In addition, the progress of the participants should be monitored by measuring the digital maturity level of them before and after the training workshops

- **Task 4:** Propose a business-plan for maintaining or increasing the momentum of the training programs after the lifespan of the subsidized project. The business-plan should live on within an ecosystem containing three types of parties: 1) Facility providers, 2) companies who can provide training, 3) supervisors and managers of on-site workers who want to improve their training skills on the use of digital technologies relevant to their filed. Moreover, given that market demand of training courses is a big barrier as proven in previous relevant projects such as BUILD UP Skills[104] developing a marketing plan to promote training courses should be an integral part of this task. Proactive promotion of training courses, direct marketing approaches, early involvement of stakeholders all have been concluded to help in marketing training courses in the construction sector.

#### 5.3.4 Indicative period and duration of roll-out

Successful implementation of this initiative depends on the implementation and outcome of the other two initiatives (digital maturity degree levels and DIHs) and should relate to other synergetic projects such as 'Skills Blueprint For The Construction Industry (Start: 01-01-2019 - End: 31-12-2022)' to benefit from the findings and identified gaps. To this end it is recommended to launch a call for the proposed action in the third quarter of 2021 for a period of 1 year.

#### 5.3.5 Intended contributors and participants of the roll-out

The team supporting the realisation of this action could present or be supported by a mix of organisations for example:

- Leading institutions in the training system of the construction sector
- Relevant public authorities
- Vocational and educational training institutions
- Private companies form building sector

### 5.4 Preliminary risk assessment and contingency plan

The table below provides a snapshot of the risks of each of the three actions and the mitigation measures to prevent that from happening. Through expert judgement Severity (of the materialising risk) has been rated: Low | Medium | High; Probability (for risk to materialise): Low | Medium | High.

| Risk | Action affected | Severity | Probability | Mitigation |
|---|---|---|---|---|

104 European Commission (2018) Final report on the assessment of the BUILD UP Skills Pillar II. Available on: http://www.buildup.eu/sites/default/files/content/bus-d4.4finareport_on_assessment_april_2018_0.pdf

| | | | | |
|---|---|---|---|---|
| Language barrier if the digital platform, tool & handbook are in English | Action I | High | High | . Simple language;<br>. Tool & handbook to be made available in other languages;<br>. Monitoring to check if the language is understandable. |
| The digital platform is not appealing / not used | Action I | High | Medium | Gamifying the campaign towards digitization makes it a social action and thus more effective and likely to sustain by asking questions, up-voting helpful answers so the platform stays alive while all participant SMEs gradually improve their maturity level interacting with each-other.<br><br>'Marketing' / promotion of tool & handbooks will be done via the platform they are part of. |
| No comprehensive understanding / agreement of the different digital maturity level in business specific areas and benchmarking | Action I | High | Medium | Getting main market players involved by the contractor in the design stage of the maturity scan (Education, Business, Umbrella organizations in business specific areas) |
| Cooperation between DIHs of different Member States does not materialize (e.g. due to local, regional, national differences in legislation, climatic conditions etc) | Action II | High | Low | Although there are differences between the Member States this problem can be solved when the DIHs cooperate on technology development that |

| | | | | |
|---|---|---|---|---|
| | | | | does not lead to such issues (e.g. like cooperating on 3D print or BIM solutions). |
| There are not enough DIHs for construction to participate in the coaching program. | Action II | High | Medium | Clear online promotion about the added value of the training for DIHs. Inviting existing DIHs to get involved as long as they focus on construction or on technologies relevant for construction. |
| Training courses are developed but not accepted by blue-collar workers | Action III | High | Medium | 'Marketing' (of training courses) is key element in the Tender Specifications of the contract to be issued. |
| The training programmes/workshops do not continue after the end of the project and the training materials are outdated | Action III | High | Medium | Proposing a business plan and an ecosystem for maintaining and increasing the momentum of the training programs after the lifespan of the subsidized project is crucial. This should be explicitly included in the tasks description in the call for proposals. |

## 5.5 Conclusions of the roll out plan

All of the three actions are proposed as top down actions that could be initiated by the Commission. On the ground work to set up a platform (Action I), DIHs (Action II) or training courses (Action III) could therefore be executed by awarded contractors.

Particularly Action III depends on Action I as the interactive handbook of Action I is input for the training courses to be developed as part on Action III. Action III is also dependent on external developments namely the results from the 'Blueprint for sectoral cooperation on skills', as the project is identifying gaps and proposing training to address those. Moreover, action III is also dependent on action II since it provides SMEs access to expertise and digital facilities. This inter-relation has been reflected in the planning proposed for the three actions.

- **For Action 1:** The digital maturity scan and the interactive handbook. However, these needs to be implemented on an existing platform to avoid that more budget is needed.

- **For Action 2:** A three-day training program for DIHs is proposed as a start.

- **For Action 3:** Conducting two rounds of training workshops with a minimum of 15 ((blue-collar workers' supervisors and trainers) participants with a practical construction challenge to be tackled using digital technologies

These actions take into account and are synergistic with ongoing activities such as explained in Action II that build further on previous DIH projects like the I4MS project, Action III with regards to the 'Skills Blueprint for The Construction Industry'.

The role of the Commission in rolling out these actions is mainly to stimulate the pan-European cooperation of DIHs and their involved partners (e.g. SMEs, large firms, knowledge and education institutes), and to stimulate the input of different Member States in the interactive handbook and skills development.

The main risks revolve around:

- The main risks for action 1 are that the platform is not appealing, or that there is no comprehensive understanding of the digital maturity level.
- The mains risks of action 2 is that there are not enough DIHs that want to participate in the three-day training program.
- The main risk for action 3 is that the training schemes are not picked up by blue collars.

The main mitigation strategies are marketing and communication for most of the three actions and involving relevant experts (from the construction sector and education) in the development of the maturity scan to be able to come to a comprehensive understanding of the maturity level.

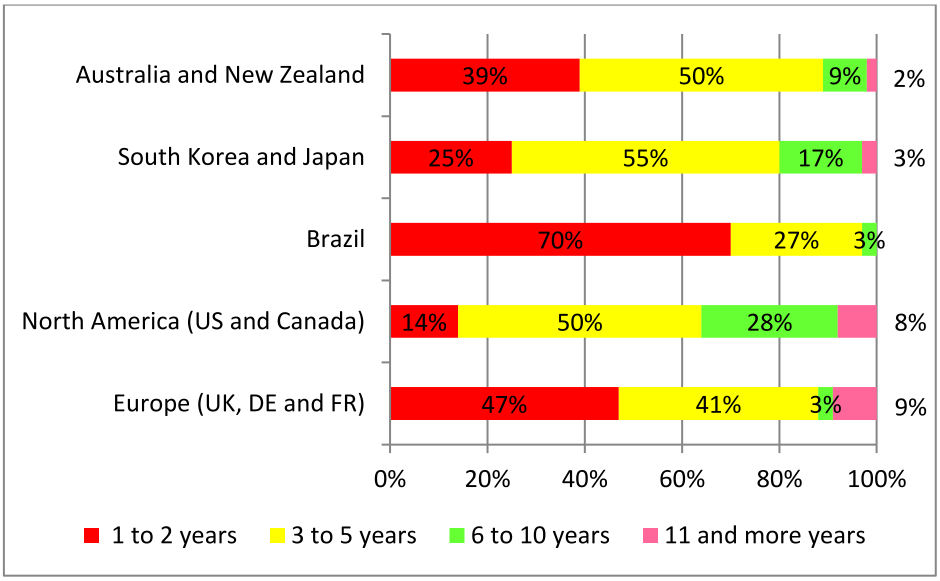
## ANNEX A: BIM PENETRATION IN MAJOR GLOBAL CONSTRUCTION MARKETS

A survey, published in 2014, gathered data on the use of BIM from 727 companies active in ten leading construction markets including France, Germany, the UK, the US and Canada, Brazil, South Korea and Japan as well as Australia and New Zealand. The survey provides information on the experience in the use of BIM, the level of BIM implementation, the level of BIM expertise as well as on the use of BIM per sub-sector and construction projects type as described below.

- **Experience in the use of BIM** measures the number of years surveyed companies have been using BIM.

The share of companies who have been using BIM for 11 years and more is almost equal in Europe (9%) and North America (8%). However, Europe has the lowest share, 3%, of companies who have been using BIM between 6 and 10 years against 28% in North America and 17% in Japan and South Korea. Similarly, Europe has the highest share of the companies who have been using BIM only between 1 and 2 years against 14% only in North America. Overall, 86% of the companies in North America reported the use of BIM for more than three years against only 53% in Europe (Figure 13).

**Figure 13: Number of years companies have been using BIM per region**

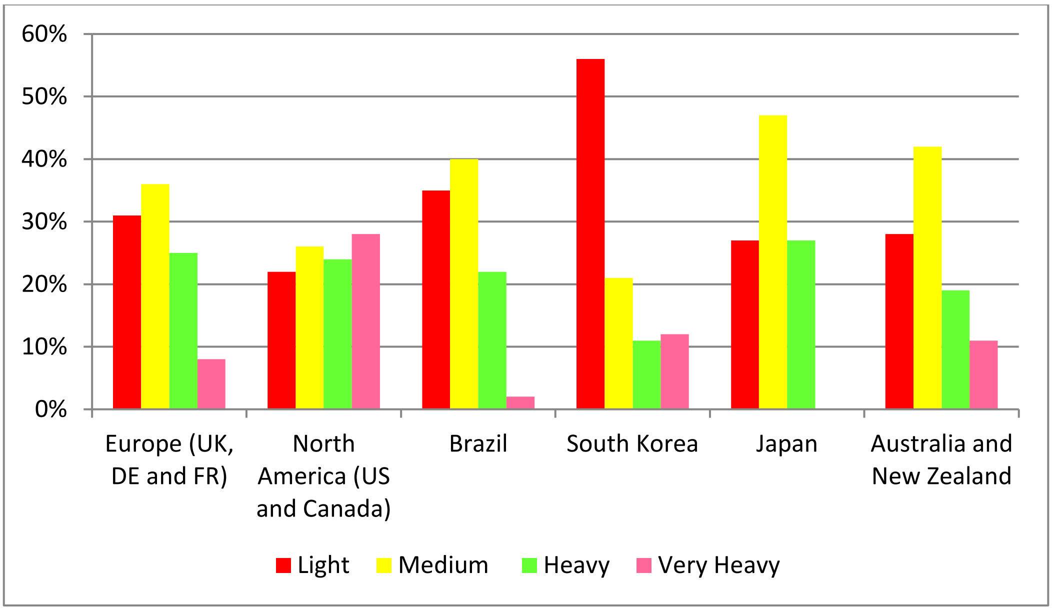



- **BIM implementation** refers to the percentage of projects for which the surveyed companies have used BIM. The survey considers four different levels of BIM implementation including:

    1. Light implementation if the company used BIM for less than 15% projects.
    2. Medium implementation if the company used BIM for more than 15% and less than 30% of its projects.
    3. Heavy implementation if the company used BIM for more than 31% and less than 59% of its projects.
    4. Very heavy implementation if the company used BIM for more than 60% of its projects.

The survey showed that BIM was heavily to very heavily used in 52% of the construction projects in North America, against 33% of the projects in the three EU countries surveyed. Furthermore, the heavy to very heavy use of BIM occurred for 30% of the construction projects in Australia and New Zealand and 27% of the projects in Japan. Brazil had the lowest very heavy use of BIM with only 2% of the projects. However, when combining the heavy and very heavy use of BIM, the share of construction projects for which BIM was used in Brazil is almost equal to South Korea (Figure 14).

**Figure 14: Level of BIM implementation in the ten leading construction markets**

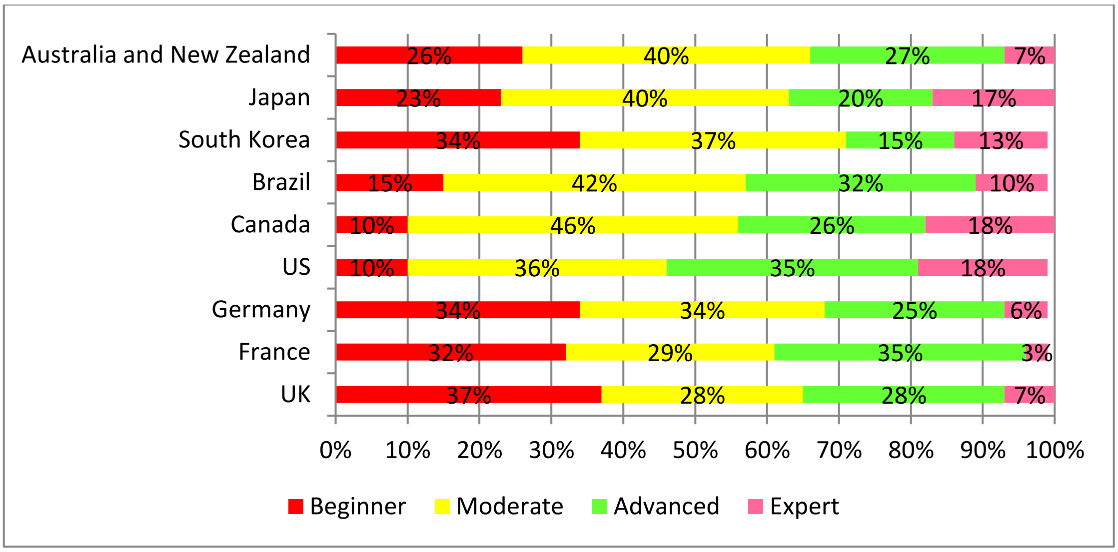



- **Level of expertise** is defined by four levels of expertise. Surveyed companies classify themselves either as beginner, moderate, advanced or expert in the use of BIM.

The survey shows that companies active in America are leading for the combined percentage of advanced and expert in the use of BIM (Figure 15). In fact, companies in the US reported the highest combined percentage (53%), followed by Canada (44%) and Brazil (43%). The highest combined percentage of advanced and expert in the use of BIM in the EU was reported by companies active in the French market (38%). It is worth noting that 35% of the companies active in the French market reported advanced use of BIM. This figure is similar to the one reported by the US companies. Furthermore, companies active in the UK reported the highest percentage of beginners, 37%. This might be due to recently adopted mandate to require the use BIM for public projects as described in the following section.

Importantly, the self-reported level of expertise in the use of BIM correlates well with the level implementation and the experience in the use of BIM. North America is leading in each of the three categories assessed.

**Figure 15: Level of BIM expertise in the ten leading construction markets**




- **Level of proficiency and use of BIM per construction sub-sectors and projects type**

The level of proficiency in the use of BIM per sub-sector varies widely across the ten leading construction markets. Companies active in the French market reported the highest proficiency levels in the use of BIM for civil engineering works (80%), followed by those active in the Japanese market (57%). The lowest proficiency level in the use of BIM in civil engineering was reported by companies active in South Korea. Regarding the sub-sector of construction of buildings, companies active in the Japanese market reported the highest proficiency level for the construction of steel buildings, 70%, followed by the companies active in the French market with 66%. South Korea is also lagging for the use of BIM in the construction of steel buildings. Companies active in the French market reported the highest proficiency level, 77%, in the use of BIM for electricity activities, followed by the companies active in the German market with 68%. Companies active in the US market reported the highest proficiency level for the use of BIM for plumbing, mechanical and sheet metal activities (Table 3).

Moreover, surveyed companies reported on their use of BIM per construction projects type. The survey shows that the strongest use of BIM occurs for the construction of commercial buildings. In fact, more than 50% of the companies reported the use of BIM for the construction of commercial buildings in all countries except South Korea which where it was slightly below (at 48%). The highest share of the companies using BIM for institutional buildings was in the US (77%), followed by the UK, with 61% while the lowest figures were reported by companies active in the Japanese market. Similarly, the highest share of companies reporting the use of BIM for the construction of public buildings was in the US with 68%, followed by the UK with 54% while companies active in the Japanese market didn’t report any use of BIM for public buildings. It is worth noting that the use of BIM for non-building projects is below 50% in all markets surveyed (Table 4).

The survey provides insight about the use of BIM per companies’ size. Large companies reported very high use of BIM, 58%, while 44% of small companies reported very low use of BIM. Unfortunately, a breakdown of this information per market is not provided by the survey. However, it is likely that similar shares apply for companies active in the European market.

**Table 3: Proficiency in the use of BIM per construction sub-sectors' activities**

| Construction sub-sector | | France | Germany | UK | US | Canada | Brazil | Japan | South Korea | Australia/ New Zealand |
|---|---|---|---|---|---|---|---|---|---|---|
| Construction of buildings | Steel | 66% | 61% | 62% | 62% | 48% | 37% | 70% | 41% | 51% |
| | Concrete/masonry | 60% | 50% | 13% | 13% | 8% | 21% | 50% | 11% | 35% |
| | Curtain wall | 50% | 58% | 21% | 21% | 31% | 32% | 43% | 35% | 27% |
| | Drywall/Ceilings | 50% | 58% | 8% | 7% | 19% | 12% | 33% | 12% | 13% |
| Civil engineering (Civil site/geotechnical) | | 80% | 52% | 21% | 12% | 38% | 39% | 57% | 7% | 46% |
| Specialised construction activities | Electricity | 77% | 68% | 18% | 35% | 35% | 16% | 60% | 10% | 36% |
| | Plumbing, mechanical, sheet metal | 63% | 61% | 24% | 66% | 38% | 24% | 50% | 24% | 57% |

**Table 4: Share of companies using BIM per construction project type**

| Construction projects type | France | Germany | UK | US | Canada | Brazil | Japan | South Korea | Australia/ New Zealand |
|---|---|---|---|---|---|---|---|---|---|
| Commercial buildings (offices, retail, hotels) | 68% | 59% | 69% | 66% | 54% | 53% | 63% | 48% | 70% |
| Institutional buildings (Education, healthcare, religious) | 32% | 31% | 61% | 77% | 41% | 31% | 23% | 35% | 39% |
| Government/Publicly owned buildings (Courthouses, embassies, civic/sports and convention) | 10% | 22% | 54% | 68% | 44% | 12% | 0% | 51% | 37% |
| Multifamily residential buildings | 35% | 44% | 33% | 18% | 26% | 19% | 23% | 20% | 26% |
| Single-family residential buildings | 19% | 22% | 17% | 1% | 10% | 16% | 0% | 1% | 4% |
| Infrastructure (roads, bridges, tunnels, dam, water/waste management) | 19% | 16% | 33% | 14% | 31% | 28% | 13% | 24% | 25% |

## ANNEX B: List of identified H2020 projects directly related to the digitalisation of the construction sector

| id Number | Project title | EU contribution (€) |
|---|---|---|
| 768774 | Energy Behaviour Change driven by plug-and-play-and-forget ICT and Business Models focusing on complementary currency for Energy Efficiency for the Wider Population | 2021502 |
| 636984 | Building energy renovation through timber prefabricated modules | 4148435 |
| 688038 | BIG IoT - Bridging the Interoperability Gap of the Internet of Things | 7999883 |
| 753994 | BIM-based EU -wide Standardized Qualification Framework for achieving Energy Efficiency Training | 993418 |
| 745510 | Towards a learning building sector by setting up a large-scale and flexible qualification methodology integrating technical, cross-craft and BIM related skills and competences | 999620 |
| 688203 | Building an IoT OPen innovation Ecosystem for connected smart objects | 7848160 |
| 732204 | Platform for Open Development of Systems of Artificial Intelligence | 5018025 |
| 637186 | Breakthrough solutions for adaptable envelopes for building refurbishment | 5849107 |
| 799149 | Laser Scanning for Automatic Bridge Assessment | 177599 |
| 637221 | Built to Specifications: Self-Inspection, 3D Modelling, Management and Quality-Check Tools for the 21st Century Construction Worksite | 5535104 |
| 754046 | Solution sets for the Cost reduction of new Nearly Zero-Energy Buildings – Con-ZEBs | 1561651 |
| 781473 | The next generation of internet-of-thing (IoT) connectivity. | 50000 |
| 723541 | Decentralised architectures for optimised operations via virtualised processes and manufacturing ecosystem collaboration | 3468313 |
| 775159 | Domo4m: Scalable Intelligent home office automation for energy savings | 50000 |
| 755134 | Intelligent Building Automation Diagnostics | 150000 |
| 763671 | Drone European AIM Study | 710435 |
| 791757 | Enterprise BIM digitization platform feasibility verification | 50000 |
| 809180 | The Professional Platform for sustainable and connected buildings | 50000 |
| 736300 | Cyber security system with a high IoT network visibility and fast vulnerability detection for Smart Homes. | 50000 |
| 792210 | Deployment of novel Geothermal systems, technologies and tools for energy efficient building retrofitting. | 7896940 |
| 710148 | Internet of Things Air Tester as a new standard based wearable monitoring station for personalized indoor and outdoor air quality real-time assessment | 50000 |

| | | |
|---|---|---|
| 723677 | Heating and Cooling: Open Source Tool for Mapping and Planning of Energy Systems | 2332804 |
| 636717 | New Easy to Install and Manufacture PRE-Fabricated Modules Supported by a BIM based Integrated Design Process. | 4539340 |
| 636063 | Intuitive Self-Inspection Techniques using Augmented Reality for construction, refurbishment and maintenance of energy-efficient buildings made of prefabricated components | 5999885 |
| 690658 | Simulation using Building Information Modelling Methodology of Multimodal, Multipurpose and Multiproduct Freight Railway Terminals Infrastructures. | 2999548 |
| 777455 | Towards smarter means of production in European manufacturing SMEs through the use of the Internet of Things technologies | 4852813 |
| 765921 | Internet of Thing for Smart Water Innovative Networks | 761644 |
| 775051 | A smart pellet stove that combines efficient heat generation with IoT | 50000 |
| 633477 | Development and advanced prefabrication of innovative, multifunctional building envelope elements for Modular Retrofitting and Connections. | 4364749 |
| 754016 | Network for Using BIM to Increase the Energy Performance | 995023 |
| 805004 | P2P Digitalisation Support to SME | 50000 |
| 775836 | Feasibility study for PassivDom – autonomous self-learning 3D-printed modular house | 50000 |
| 783944 | AN INTELLIGENT PREDICTION SYSTEM FOR THE SMART EFFICIENT USE OF RESOURCES IN CITIES | 1301213 |
| 746215 | Preserving Wooden Heritage. Methods for monitoring wooden structures: 3D laser scanner survey and application of BIM systems on point cloud models | 179326 |
| 737459 | Electronics and ICT as enabler for digital industry and optimized supply chain management covering the entire product lifecycle | 26033148 |
| 737757 | Sustainable Prefabricated Glass Façade with Performance Exceeding State-of-the-art Glass Façades | 2497532 |
| 768619 | RESPOND: integrated demand Response Solution towards energy Positive Neighbourhoods | 3044710 |
| 702874 | Simulations for multi-level Analysis of interactions in Tunnelling based on the Building Information Modelling technology | 195455 |
| 665091 | Multimodal Scanning of Cultural Heritage Assets for their multi-layered digitization and preventive conservation via spatiotemporal 4D Reconstruction and 3D Printing | 3417762 |
| 672124 | An Innovative ICT Solution for Providing Bespoke Safety and Health Training to Workers in the Construction and Transportation Sectors. | 50000 |
| 763308 | Upgrading Railways from the Air | 50000 |
| 684086 | Smart interoperable electronic active valve control eco-system and service to achieve superior building efficiency and user awareness | 1611400 |

| | | |
|---|---|---|
| 714087 | Big Data for 4D Global Urban Mapping – 10^16 Bytes from Social Media to EO Satellites | 1496500 |
| 777112 | Smart Water Management Platform | 1478090 |
| 768936 | Temperature Optimisation for Low Temperature District Heating across Europe | 4064099 |
| 718742 | Automated 3D Thermal Imaging of Industrial Plants and Residential Buildings by Drones | 50000 |
| 637624 | Woven and 3D-Printed Thermoelectric Textiles | 1500000 |
| 650206 | A Thermal-Visual Integrated System Mounted on an Unmanned Aerial Vehicle for 3D energy performance mapping and forecasting and damage evaluation | 50000 |
| 785005 | Toward market-based skills for sustainable Energy Efficient construction | 877006 |
| 732078 | User Engagement for Large Scale Pilots in the Internet of Things | 998625 |
| 688467 | Open virtual neighbourhood network to connect intelligent buildings and smart objects | 7499008 |
| 666610 | Volumental - The Cloud-Delivered 3D Scanning Service Supporting A Future Of Mass Customization | 1460900 |
| 739524 | Numerical modelling of reinforced slender wooden window elements | 50473 |

## **ANNEX C:** LIST OF LITERATURE

| *Type* | *Author* | *Year* | *Title* |
|---|---|---|---|
| *Report* | *McGraw Hill* | *2010* | *The business value of BIM in Europe* |
| *Report* | *PWC* | *2011* | *Measuring industry digitization* |
| *Presentation* | *Microsoft* | *2013* | *Transforming Buildings: Data, Cloud, Software Tools* |
| *Journal article* | *Cao et al.* | *2014* | *Practices and effectiveness of building information modelling in construction projects in China* |
| *Report* | *EP* | *2014* | *DIRECTIVE 2014/24/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 February 2014 on public procurement and repealing Directive 2004/18/EC* |
| *Report* | *EP* | *2014* | *DIRECTIVE 2014/25/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 February 2014 on procurement by entities operating in the water, energy, transport and postal services sectors and repealing Directive 2004/17/EC* |
| *Journal article* | *Ergen et al.* | *2014* | *Blockage assessment of buildings during emergency using multiple types of sensors* |
| *Journal article* | *Ham & Golparvar-Fard* | *2014* | *Mapping actual thermal properties to building elements in gbXML-based BIM for reliable building energy performance modeling* |
| *Journal article* | *Hamzeh et al.* | *2014* | *Understanding the role of "tasks anticipated" in lookahead planning through simulation* |
| *Journal article* | *Kim et al.* | *2014* | *A framework for dimensional and surface quality assessment of precast concrete elements using BIM and 3D laser scanning* |
| *Journal article* | *Kim et al.* | *2014* | *Developing a physical BIM library for building thermal energy simulation* |
| *Report* | *McGraw Hill* | *2014* | *The business value of BIM for construction in major global markets* |
| *Presentation* | *PWC* | *2014* | *BIM-Enabled lean construction* |
| *Report* | *PWC* | *2014* | *Real estate 2020 - Building the future* |
| *Journal article* | *Sousa & Xavier* | *2014* | *Symmetry-based generative design and fabrication: A teaching experiment* |
| *Journal article* | *Sun et al.* | *2014* | *IFCCompressor: A content-based compression algorithm for optimizing Industry Foundation Classes files* |

| | | | |
|---|---|---|---|
| *Report* | *Arch-Vision* | *2015* | *The United Kingdom and the Netherlands are clearly at the forefront when it comes to Building Information Modeling in Europe* |
| *Conference article* | *Barry McAuley et al.* | *2015* | *Collaborative Public Works Contracts using BIM – An Opportunity for the Irish Construction Industry* |
| *Journal article* | *Cemesova et al.* | *2015* | *PassivBIM: Enhancing interoperability between BIM and low energy design software* |
| *Journal article* | *Corry et al.* | *2015* | *A performance assessment ontology for the environmental and energy management of buildings* |
| *Journal article* | *Costa & Madrazo* | *2015* | *Connecting building component catalogues with BIMmodels using semantic technologies: an application for precast concrete components* |
| *Journal article* | *Gattas & You* | *2015* | *Design and digital fabrication of folded sandwich structures* |
| *Journal article* | *Gimenez et al.* | *2015* | *Automatic reconstruction of 3D building models from scanned 2D floor plans* |
| *Journal article* | *Han & Golparvar-Fard* | *2015* | *Appearance-based material classification for monitoring of operation-level construction progress using 4D BIM and site photologs* |
| *Journal article* | *Heydarian et al.* | *2015* | *Immersive virtual environments versus physical built environments: A benchmarking study for building design and user-built environment explorations* |
| *Journal article* | *Johansson et al.* | *2015* | *Real-time visualization of building information models (BIM)* |
| *Journal article* | *Karan & Irizarry* | *2015* | *Extending BIM interoperability to preconstruction operations using geospatial analyses and semantic web services* |
| *Web article* | *Kenny Ingram* | *2015* | *Digitizing the construction industry is bigger than BIM* |
| *Journal article* | *Kumar & Cheng* | *2015* | *A BIM-based automated site layout planning framework for congested construction sites* |
| *Presentation* | *Lafarge Holcim* | *2015* | *3D Printing* |
| *Journal article* | *Lee* | *2015* | *Re-informative design media in design emergence* |
| *Journal article* | *Lee et al.* | *2015* | *Modularized rule-based validation of a BIMmodel pertaining to model views* |
| *Journal article* | *Liu et al.* | *2015* | *A BIM-aided construction waste minimisation framework* |

| | | | |
|---|---|---|---|
| *Journal article* | *Love et al.* | *2015* | *Future proofing PPPs: Life-cycle performance measurement and Building Information Modelling* |
| *Journal article* | *Marzouk & Abubakr* | *2015* | *Decision support for tower crane selection with building information models and genetic algorithms* |
| *Journal article* | *Oraskari & Torma* | *2015* | *RDF-based signature algorithms for computing differences of IFC models* |
| *Journal article* | *Pauwels & Terkaj* | *2015* | *EXPRESS to OWL for construction industry: Towards a recommendable and usable ifcOWL ontology* |
| *Journal article* | *Radulovic et al.* | *2015* | *Guidelines for Linked Data generation and publication: An example in building energy consumption* |
| *Journal article* | *Succar & Kassem* | *2015* | *Macro-BIM adoption: Conceptual structures* |
| *Journal article* | *Tixier et al.* | *2015* | *"Automated content analysis for construction safety: A natural language processing system to extract precursors and outcomes from* |
| *unstructured injury reports"* | | | |
| *Journal article* | *Vahdatikhaki & Hammad* | *2015* | *Risk-based look-ahead workspace generation for earthwork equipment using near real-time simulation* |
| *Journal article* | *Wang et al.* | *2015* | *Applying building information modeling to support fire safety management* |
| *Journal article* | *Williams et al.* | *2015* | *FabPod: Designing with temporal flexibility & relationships to mass-customisation* |
| *Journal article* | *Willmann et al.* | *2015* | *Robotic timber construction — Expanding additive fabrication to new dimensions* |
| *Journal article* | *Yu & LI* | *2015* | *Virtual in-situ calibration method in building systems* |
| *Journal article* | *Zibin et al.* | *2015* | *Automatic assisted calibration tool for coupling building automation system trend data with commissioning* |
| *Report* | *Arch-Vision* | *2016* | *Manufacturers have to make their BIM product information available in open source libraries* |
| *Report* | *BCG* | *2016* | *Digital in engineering and construction* |
| *Journal article* | *Biagini et al.* | *2016* | *Towards the BIM implementation for historical building restoration sites* |
| *Journal article* | *Bradley et al.* | *2016* | *BIM for infrastructure: An overall review and constructor perspective* |

| | | | |
|---|---|---|---|
| *Journal article* | *Chang et al.* | *2016* | *COMPUTATIONAL DESIGN in the past, present and future of digital architecture* |
| *Journal article* | *Chen et al.* | *2016* | *A cloud-based system framework for performing online viewing, storage, and analysis on big data ofmassive BIMs* |
| *Journal article* | *Chen et al.* | *2016* | *Building HVAC control knowledge data schema – Towards a unified representation of control system knowledge* |
| *Journal article* | *Cheng et al.* | *2016* | *Analytical review and evaluation of civil information modeling* |
| *Journal article* | *Choi et al.* | *2016* | *Development ofopenBIM-based energy analysis software to improve the interoperability of energy performance assessment* |
| *Journal article* | *Datta et al.* | *2016* | *Computation and fabrication of scaled prototypes* |
| *Journal article* | *Du et al.* | *2016* | *Virtual operator modeling method for excavator trenching* |
| *Report* | *EC* | *2016* | *Digitising European Industry-Reaping the full benefits of a Digital Single Market* |
| *Journal article* | *Fuchs & Scherer* | *2016* | *Multimodels — Instant nD-modeling using original data* |
| *Journal article* | *Fukuda et al.* | *2016* | *A dynamic physical model based on a 3D digital model for architectural rapid prototyping* |
| *Web article* | *Grégoire Normand* | *2016* | *En Europe, l'impression 3D fait couler de l'encre* |
| *Journal article* | *Hamledari et al.* | *2016* | *Automated computer vision-based detection of components of under-construction indoor partitions* |
| *Journal article* | *Holzer* | *2016* | *Design exploration supported by digital tool ecologies* |
| *Report* | *IDEA et al.* | *2016* | *Identifying current and future application areas, existing industrial value chains and missing competences in the EU, in the area of additive manufacturing (3D-printing)* |
| *Journal article* | *Ilhan & Yaman* | *2016* | *Green building assessment tool (GBAT) for integrated BIM-based design decisions* |
| *Journal article* | *Johnston et al.* | *2016* | *An assessment of pictographic instructions derived from a virtual prototype to support construction assembly procedures* |
| *Journal article* | *Jovanovic et al.* | *2016* | *Robotic fabrication of freeform foam structures with quadrilateral and puzzle shaped panels* |

| | | | |
|---|---|---|---|
| *Journal article* | *Kang et al.* | *2016* | *Managing construction schedule by telepresence: Integration of site video feed with an active nD CAD simulation* |
| *Journal article* | *Kim et al.* | *2016* | *Automated dimensional quality assurance of full-scale precast concrete elements using laser scanning and BIM* |
| *Journal article* | *Le & Jeong* | *2016* | *Interlinking life-cycle data spaces to support decisionmaking in highway asset management* |
| *Journal article* | *Lee et al.* | *2016* | *Streamlining Digital Modeling and Building Information Modelling (BIM) Uses for the Oil and Gas Projects* |
| *Journal article* | *Liao & Lee* | *2016* | *Detection of rust defects on steel bridge coatings via digital image recognition* |
| *Journal article* | *Linderoth et al.* | *2016* | *From visions to practice: The role of sensemaking institutional logic and pragmatic practice* |
| *Report* | *McKinsey* | *2016* | *Imagining construction's digital future* |
| *Journal article* | *Meehan et al.* | *2016* | *Assessing soil compaction using continuous compaction control and location-specific in situ tests* |
| *Web article* | *Michael Shomberg* | *2016* | *How Digitization Is Disrupting Construction: Strategies Forward* |
| *Newsletter* | *N/A* | *2016* | *European construction machinery sector embraces digital transformation as driver of success* |
| *Report* | *N/A* | *2016* | *Action Plan on Construction - Contribution on digitalisation* |
| *Journal article* | *Oti et al.* | *2016* | *A framework for the utilization of Building Management System data in building information models for building design and operation* |
| *Journal article* | *Oti et al.* | *2016* | *Structural sustainability appraisal in BIM* |
| *Journal article* | *Parn et al.* | *2016* | *The building information modelling trajectory in facilities management: A review* |
| *Journal article* | *Perisic et al.* | *2016* | *The Extensible Orchestration Framework approach to collaborative design in architectural, urban and construction engineering* |
| *Report* | *PWC* | *2016* | *Industry 4-0 Building the digital enterprise - Engineering and construction key findings* |
| *Report* | *PWC* | *2016* | *Engineering and construction industry trends* |
| *Report* | *PWC* | *2016* | *Industry 4.0 Building the digital enteprise* |

| | | | |
|---|---|---|---|
| *Report* | *Roland Berger* | *2016* | *Digitization in the construction industry* |
| *Journal article* | *Skandhakumar et al.* | *2016* | *Graph theory based representation of building information models for access control applications* |
| *Journal article* | *Sweet* | *2016* | *Resurrecting the master builder: A pedagogical strategy for robotic construction* |
| *Journal article* | *Wang et al.* | *2016* | *Automated quality assessment of precast concrete elements with geometry irregularities using terrestrial laser scanning* |
| *Journal article* | *Want et al.* | *2016* | *Applying building information modeling to integrate schedule and cost for establishing construction progress curves* |
| *Web article* | *WEF* | *2016* | *What's the future of the construction industry?* |
| *Report* | *WEF* | *2016* | *Shaping the future of construction: A breakthrough in mindset and technology* |
| *Journal article* | *Won & Lee* | *2016* | *How to tell if a BIM project is successful: A goal-driven approach* |
| *Journal article* | *Zakeri et al.* | *2016* | *Rahbin: A quadcopter unmanned aerial vehicle based on a systematic image processing approach toward an automated asphalt pavement inspection* |
| *Journal article* | *Zikos et al.* | *2016* | *Conditional Random Fields - based approach for real-time building occupancy estimation with multi-sensory networks* |
| *Report* | *Accenture* | *2017* | *Building construction growth with digital bricks and mortar* |
| *Journal article* | *Alves et al.* | *2017* | *BIMSL: A generic approach to the integration of building information models with real-time sensor data* |
| *Journal article* | *Balado et al.* | *2017* | *Automatic building accessibility diagnosis from point clouds* |
| *Report* | *BPIE* | *2017* | *Is Europe ready for the smart buildings revolution?* |
| *Report* | *BPIE* | *2017* | *Opening the door to smart buildings* |
| *Report* | *BPIE* | *2017* | *Smart buildings decoded* |
| *Presentation* | *Brashnarov* | *2017* | *"Digitization of construction: an open ecosystem for digital SMEs* |
| *to serve the construction sector"* | | | |
| *Journal article* | *Bruno et al.* | *2017* | *Historic Building Information Modelling: performance assessment for diagnosis-aided information modelling and management* |

| | | | |
|---|---|---|---|
| *Presentation* | *buildingSMART* | *2017* | *buildingSMART briefing for EC* |
| *Presentation* | *buildingSMART* | *2017* | *buildingSMART Data Dictionary* |
| *Report* | *buildingSMART* | *2017* | *buildingSMART Data Strategy-Objectives* |
| *Journal article* | *Cavka et al.* | *2017* | *Developing owner information requirements for BIM-enabled project delivery and asset management* |
| *Journal article* | *Chen & Wang* | *2017* | *Automatic key frame extraction in continuous videos from construction monitoring by using color, texture, and gradient features* |
| *Journal article* | *Chu et al.* | *2017* | *Integrating mobile Building Information Modelling and Augmented Reality systems: An experimental study* |
| *Journal article* | *Craveiro et al.* | *2017* | *A design tool for resource-efficient fabrication of 3d-graded structural building components using additive manufacturing* |
| *Journal article* | *Buffat at al.* | *2017* | *GIS-based decision support for building retrofit* |
| *Web article* | *Denis Branthonne* | *2017* | *Can the Construction Industry Catch Up on Digitization?* |
| *Presentation* | *DG CNECT* | *2017* | *Digitising European Industry* |
| *Meeting agenda* | *DG GROW* | *2017* | *High Level Tripartite Strategic Forum, 5th Meeting* |
| *Meeting agenda* | *DG GROW* | *2017* | *High Level Tripartite Strategic Forum, 6th Meeting* |
| *Meeting minutes* | *DG GROW* | *2017* | *Thematic Group 1 "Stimulating investment in building renovation, infrastructure and innovation", Meeting Minutes* |
| *Meeting minutes* | *DG GROW* | *2017* | *High Level Tripartite Strategic Forum, 6th Meeting Minutes* |
| *Meeting minutes* | *DG GROW* | *2017* | *High Level Tripartite Strategic Forum, 6th Meeting Minutes V2* |
| *Report* | *DG RTD* | *2017* | *Transforming European industry and services* |
| *Workshop* | *Digital Europe* | *2017* | *Digital in Practice Workshop title "Construction 4.0 – Once in a generation opportunity"* |
| *Journal article* | *Du et al.* | *2017* | *Zero latency: Real-time synchronization of BIM data in virtual reality for collaborative decision-making* |
| *Presentation* | *Dumitru* | *2017* | *Perspectives of BIM implementation in Romania* |
| *Presentation* | *EBC* | *2017* | *"Construction SMEs perspective on digitalisation* |

| | | | |
|---|---|---|---|
| *Needs, opportunities, barriers"* | | | |
| *Communication* | *EC* | *2017* | *Investing in a smart, innovative and sustainable Industry A renewed EU Industrial Policy Strategy* |
| *Presentation* | *EC* | *2017* | *Investing in a smart, innovative and sustainable industry* |
| *Report* | *EC* | *2017* | *Digitising European industry: Progress so far, 18 months after the launch* |
| *Presentation* | *EC* | *2017* | *Thematic Group 1 "Stimulating investment in building renovation, infrastructure and innovation"* |
| *Presentation* | *EC* | *2017* | *"Stimulating Investments in Building Renovation, Infrastructure and* |
| *Innovation"* | | | |
| *Web article* | *Economist* | *2017* | *"Least-improved* |
| *Efficiency eludes the construction industry"* | | | |
| *Report* | *ECSO* | *2017* | *Policy measure fact sheet - Lithuania* |
| *Web article* | *Erick Haehnsen* | *2017* | *Renforcer la cohérence des filières industrielles* |
| *Report* | *EUBIM* | *2017* | *Handbook for the introduction of Building Information Modelling by the European Public Sector* |
| *Journal article* | *Evchina & Lastra* | *2017* | *An approach to combining related notifications in large-scale building management systems with a rehabilitation facility case study* |
| *Journal article* | *Fazel & Izadi* | *2017* | *An interactive augmented reality tool for constructing free-form modular surfaces* |
| *Web article* | *Gicquiau* | *2017* | *Des maisons «Lego», écolo et pas chères, construites en moins de 4 mois* |
| *Journal article* | *Hautala et al.* | *2017* | *Digitalisation transforms the construction sector throughout asset's life-cycle from design to operation and maintenance* |
| *Journal article* | *Isaac et al.* | *2017* | *Work packaging with BIM* |
| *Report* | *JBKnowledge* | *2017* | *2017 The 6th annual construction technology report* |
| *Journal article* | *Kassem & Succar* | *2017* | *Macro BIM adoption: Comparative market analysis* |

| | | | |
|---|---|---|---|
| *Journal article* | *Kivimaa & Martiskainen* | *2017* | *Innovation, low energy buildings and intermediaries in Europe: systematic case study review* |
| *Journal article* | *Kropp et al.* | *2017* | *Interior construction state recognition with 4D BIM registered image sequences* |
| *Journal article* | *Lee et al.* | *2017* | *BIM-assisted labor productivity measurement method for structural formwork* |
| *Journal article* | *Leviäkangas et al.* | *2017* | *Keeping up with the pace of digitization: the case of the australian construction industry* |
| *Journal article* | *Li et al.* | *2017* | *Mapping the knowledge domains of Building Information Modeling (BIM): A bibliometric approach* |
| *Journal article* | *Lilis & Kayal* | *2017* | *A secure and distributed message oriented middleware for smart building applications* |
| *Web article* | *Luca Moscardi* | *2017* | *The digitization of the construction industry* |
| *Journal article* | *Mansuri et al.* | *2017* | *Building Information Modeling enabled Cascading Formwork Management Tool* |
| *Journal article* | *Maruyama* | *2017* | *Tripping risk evaluation system based on human behavior simulation in laser-scanned 3D as-is environments* |
| *Journal article* | *Maurer et al.* | *2017* | *Machine-code functions in BIM for cost-effective high-quality buildings* |
| *Journal article* | *McGlinn et al.* | *2017* | *Usability evaluation of a web-based tool for supporting holistic building energy management* |
| *Report* | *McKinsey* | *2017* | *Reinventing construction-A route to higher productivity* |
| *Web article* | *Molga* | *2017* | *Les smart buildings réorganisent l'industrie du bâtiment* |
| *Web article* | *N/A* | *2017* | *World's first' 3D printed bike bridge opens in Brabant* |
| *Web article* | *N/A* | *2017* | *L'Europe se dote d'un cadre pour la construction durable* |
| *Web article* | *N/A* | *2017* | *Le CSTB fait un pas de plus en faveur de la transition numérique du bâtiment* |
| *Journal article* | *Niknam & Karshenas* | *2017* | *A shared ontology approach to semantic representation of BIM data* |
| *Journal article* | *Papadonikolaki et al.* | *2017* | *Formal and informal relations within BIM-enabled supply chain partnerships* |
| *Journal article* | *Park & Cai* | *2017* | *WBS-based dynamic multi-dimensional BIM database for total construction as-built documentation* |

| | | | |
|---|---|---|---|
| *Journal article* | *Parn & Edwards* | *2017* | *Conceptualising the FinDD API plug-in: A study of BIM-FM integration* |
| *Journal article* | *Parn and Edwards* | *2017* | *Vision and advocacy of optoelectronic technology developments in the AECO* |
| *Journal article* | *Parn et al.* | *2017* | *Origins and probabilities of MEP and structural design clashes within a federated BIM model* |
| *Journal article* | *Petri et al.* | *2017* | *Coordinating multi-site construction projects using federated clouds* |
| *Journal article* | *Pishdad-Bozorgi et al.* | *2017* | *Planning and developing facility management-enabled building information model (FM-enabled BIM)* |
| *Report* | *PWC* | *2017* | *Engineering and construction industry trends* |
| *Report* | *PWC* | *2017* | *Thriving on disruption* |
| *Report* | *Roland Berger* | *2017* | *The disruptive impact of Building Information Modeling (BIM)* |
| *Conference article* | *Ruben Santos et al.* | *2017* | *Building Information Modelling in Portugal-Methodological Guide for Energy Analysis* |
| *Journal article* | *Santos et al.* | *2017* | *Bibliometric analysis and review of Building Information Modelling literature published between 2005 and 2015* |
| *Journal article* | *Shrestha & Jeong* | *2017* | *Computational algorithm to automate as-built schedule development using digital daily work reports* |
| *Journal article* | *Solihin et al.* | *2017* | *Multiple representation approach to achieve high-performance spatial queries of 3D BIM data using a relational database* |
| *Journal article* | *Tepavcevic* | *2017* | *Design to fabrication method of thin shell structures based on a friction-fit connection system* |
| *Journal article* | *Vass & Gustavsson* | *2017* | *Challenges when implementing BIM for industry change* |
| *Journal article* | *Wei et al.* | *2017* | *BIM-based method calculation of auxiliary materials required in housing construction* |
| *Report* | *WG2* | *2017* | *Digitising European Industry* |
| *Journal article* | *Won & Cheng* | *2017* | *Identifying potential opportunities of building information modeling for construction and demolition waste management and minimization* |
| *Journal article* | *Xu et al.* | *2017* | *Digital reproduction of historical building ornamental components: From 3D scanning to 3D printing* |
| *Journal article* | *Zhao* | *2017* | *A scientometric review of global BIM research: Analysis and visualization* |

| | | | |
|---|---|---|---|
| *Journal article* | *Zhao et al.* | *2017* | *Dynamics research on grouping characteristics of a shield tunneling machine's thrust system* |
| *Journal article* | *Zhou et al.* | *2017* | *Formulating project-level building information modeling evaluation framework from the perspectives of organizations: A review* |
| *Journal article* | *Zhu et al.* | *2017* | *Integrated detection and tracking of workforce and equipment from construction jobsite videos* |
| *Journal article* | *Zielina et al.* | *2017* | *Planning the reconstruction of a historical building by using a fuzzy stochastic network* |
| *Web article* | *Richard Mac Partland* | *2017* | *What is an Asset Information Model* |
| *Presentation* | *Brantova* | *2018* | *Urban Agenda for the EU - Public Feedback Outcomes* |
| *Journal article* | *Camacho et al.* | *2018* | *Applications of additive manufacturing in the construction industry – A forward-looking review* |
| *Presentation* | *Carlén* | *2018* | *Using ICT in construction and property management* |
| *Journal article* | *Cheng et al.* | *2018* | *Developing an evacuation evaluation model for offshore oil and gas platforms using BIM and agent-based model* |
| *Journal article* | *Choi et al.* | *2018* | *Characteristics of volume change and heavy metal leaching in mortar specimens recycled heavyweight waste glass as fine aggregate* |
| *Journal article* | *Dallasega et al.* | *2018* | *A Lean Approach for Real-Time Planning and Monitoring in Engineer-to-Order Construction Projects* |
| *Report* | *ECSO* | *2018* | *Policy measure fact sheet - Slovakia - Construction information system* |
| *Report* | *ECSO* | *2018* | *Country profile Greece* |
| *Report* | *ECSO* | *2018* | *Policy measure fact sheet - Croatia* |
| *Report* | *ECSO* | *2018* | *Policy measure fact sheet - Estonia* |
| *Report* | *ECSO* | *2018* | *Policy measure fact sheet Latvia* |
| *Report* | *FHI* | *2018* | *Deciphering China's AI Dream* |
| *Journal article* | *Garcia de Soto et al.* | *2018* | *Productivity of digital fabrication in construction: Cost and time analysis of a robotically built wall* |
| *Journal article* | *Hamid et al.* | *2018* | *BIM semantics for digital fabrication: A knowledge-based approach* |

| | | | |
|---|---|---|---|
| *Journal article* | *Groppi et al.* | *2018* | *A GIS-based model to assess energy consumption and usable solar energy potential in urban areas* |
| *Web article* | *Le Monde Economie* | *2018* | *PME, la fracture numérique* |
| *Journal article* | *Li & Lu* | *2018* | *Integrating geometric models, site images and GIS based on Google Earth and Keyhole Markup Language* |
| *Web article* | *Lozano* | *2018* | *Poussé par les startups, l'immobilier rattrape son retard en matière d'innovation* |
| *Journal article* | *Mangal & Cheng* | *2018* | *Automated optimization of steel reinforcement in RC building frames using building information modeling and hybrid genetic algorithm* |
| *Journal article* | *Martin-Garin* | *2018* | *Environmental monitoring system based on an Open Source Platform and the Internet of Things for a building energy retrofit* |
| *Web article* | *N/A* | *2018* | *Planification des chantiers : passez au BIM 4D !* |
| *Journal article* | *Nascimento et al.* | *2018* | *Exploring the synergies between BIM and lean for visual construction management* |
| *Web article* | *Par Jean-Christophe de Wasseige* | *2018* | *Une start-up belge robotise ses constructions* |
| *Journal article* | *Park et al.* | *2018* | *The structure and knowledge flow of building information modeling based on patent citation network analysis* |
| *Webcast* | *PWC* | *2018* | *Global Digital Operations Study 2018 press conference and webcast* |
| *Report* | *PWC* | *2018* | *Baubranche aktuell Wachstum 2020 – Digitalisierung und BIM* |
| *Journal article* | *Volk et al.* | *2018* | *Deconstruction project planning of existing buildings based on automated acquisition and reconstruction of building information* |
| *Web article* | *WEF* | *2018* | *One-quarter of Dubai's buildings will be 3D printed by 2025* |
| *Report* | *WEF* | *2018* | *Eight futures of work - Scenarios and their implications* |
| *Report* | *WEF* | *2018* | *"An Action Plan to solve the Industry's* |
| *Talent Gap"* | | | |
| *Web article* | *Designing Buildings Wiki* | *2018* | *Asset Information Model* |

| | | | |
|---|---|---|---|
| *Journal article* | *Woodhead et al.* | *2018* | *Digital construction: From point solutions to IoT ecosystem* |
| *Journal article* | *Xu et al.* | *2018* | *Post-earthquake fire simulation considering overall seismic damage of sprinkler systems based on BIM and FEMA P-58* |
| *Journal article* | *Yamg et al.* | *2018* | *Multi-disciplinary and multi-objective optimization problem re-formulation in computational design exploration: A case of conceptual sports building design* |
| *Report* | *Aconex et al.* | *N/A* | *Five Keys to Unlocking Digital Transformation in Engineering & Construction* |
| *Conference article* | *Arshad* | *N/A* | *Automated Horizontal Building Construction – A new Paradigm* |
| *Presentation* | *ARUP* | *N/A* | *Artificial Intelligence – high tech evolution in Construction* |
| *Report* | *AutoDesk* | *N/A* | *Cracking the code for AEC business success* |
| *Presentation* | *Bock & Linner* | *N/A* | *Construction products future high tech evolution: Construction robotics* |
| *Presentation* | *Brell-Cokcan* | *N/A* | *Digital automated systems* |
| *Report* | *COWI* | *N/A* | *3D models of infrastructure will soon be a prerequisite for maintenance work* |
| *Presentation* | *CPA* | *N/A* | *BIM + Digitalisation+ CPA* |
| *Presentation* | *DG ENER* | *N/A* | *EBPD revision: Smart Readiness Indicator for Buildings* |
| *Presentation* | *EC DG GROW* | *2018* | *Commission initiatives for the modernization of construction* |
| *Presentation* | *TNO* | *2018* | *BIM implementation in EU member states and other regions and expected developments* |
| *Presentation* | *EC EASME* | *2018* | *Horizon 2020 support for BIM in energy efficient buildings* |

## ANNEX D: INTERVIEW QUESTIONS DEFINED BY MAIN TOPIC AREAS

In parallel to the selection of interview partners, the consortium developed an interview sheet containing questions defined in 6 main topic areas, as seen below. As our aim was to gain deeper insight into the current state of using digitalisation in construction, and to detect personal opinions about what could improve the situation, we used an open conversation style of conducting the interviews: We asked the interviewee first according to the 6 defined main areas and noted opinions and answers; If more information was needed, we used the specific questions to get more detail.

Developed questions have been approved by the commission beforehand. Questions cover – besides background specifications – requests about current experience for digitalisation in the interviewee's field, and challenges they faced, opinions about current EU initiatives, and where / why they work or fail. The interview included questions regarding the future perspectives and next steps, skill development and legal boundary conditions. Interviews took place in June / July 2018 via Skype and lasted at least 30 minutes.

As answers were audio recorded, we collected a signed consent form from our interview partners, stating necessary information about the project and further treatment with collected data, to ensure ethical correctness of the study. Audio recorded answers were then transcribed to be qualitatively analysed afterwards, using inductive thematic analysis. For each answer, we detected "signal words" to reveal key themes revealing trends, which we present in following summaries.

### *1. Background*

a. Role of the interviewee

b. Size of the company

### *2. Current experience with digitalisation:*

a. How they define digitalisation

b. Degree of digitalisation for construction at present

c. Since when working on digitalisation in construction

d. How introduced to digitalisation

e. How has digitalisation been used in the company's context

f. Rate of successfully finished projects

g. Detected changes in workflow, positive / negative

h. Detected benefits / drawbacks of digital tools

i. Does digitalisation improve the productivity of the company? If yes by how much?

j. What are the effects of digitalisation on employment?

k. Detected necessity for digitalisation per stage for further development to optimize workflow etc…

l. Till when this should be achieved

***3. Challenges the company faced / for SMEs to adapt to digitalisation in construction***

a. Legal

b. Technical

c. Staff skills

***4. Opinions on existing Initiatives (from EU, etc…)***

a. Pros and cons

b. Limitations & opportunities

c. Expected increasing engagement & what is missing

d. Expected role of EU in this discussion

***5. Boundary conditions***

a. Level of awareness of digital innovations and would this be supportive

b. Level of legal guidance for digital innovations

***6. Opinion about innovation possibilities***

a. Interested in more space for experimentation and implementation of digital technologies?

b. Would they invest / like to see more investment in R&D for digitalisation in construction sector and would this be supportive?

c. Current state and what skills should be improved

d. Would an intensified skills development be supportive?

e. Interest and capacity from market players to contribute to future tenders

f. Possible acceptance of a new/extended digital or institutional platform

## ANNEX E: LIST OF INTERVIEWEES

This list shows details about the interviewees that have been questioned during this report as part of Chapter II, including the Organisation the Country. Personal details, such as the Name, have been anonymized.

| Interviewee | Organisation | Country |
|---|---|---|
| 1 | *Transparent Business Institute* | Finland |
| 2 | *VTT Technical Research Centre of Finland Ltd* | Finland |
| 3 | *VTT Technical Research Centre of Finland Ltd* | Finland |
| 4 | *CSTB - Centre Scientifique et Technique du Bâtiment* | France |
| 5 | *Nemetschek Bulgaria* | Bulgaria |
| 6 | *PRODBIM* | France |
| 7 | *AIT - Austrian Institute of Technology* | Austria |
| 8 | *Fedspinoff* | Italy |
| 9 | *TU Dresden - Institute of Construction Informatics* | Germany |
| 10 | *Boydens Engineering* | Belgium |
| 11 | *Madaster* | Netherlands |
| 12 | *NBBJ* | International (UK, China, USA, India) |
| 13 | *Brydenwood* | UK |
| 14 | *BIMobject* | Sweden |
| 15 | *AIT - Austrian Institute of Technology* | Austria |
| 16 | *FIEC – European Construction Industry Federation* | Belgium |
| 17 | *EBC – European Builders Confederation* | Belgium |

## ANNEX F: GAP OVERVIEW

| No. | Gaps* | Type of challenge | Actions |
|---|---|---|---|
| 1 | Digitalisation targets are lacking at EU and national levels | Baseline & monitoring | Introducing digitalisation targets in the procurement directive and establishing requirements for the use of public funding |
| 2 | Limited capability of SMEs for digitalisation in the construction sector | | Introduce an Interactive handbook and digital maturity scan for the adoption and implementation of digital technologies |
| 3 | Market failure and lack of cooperation on Member States level that hinders the digital transformation on European level | Technical & financial measures | Facilitate the setup of DIHs for construction and link them in a pan-European network. |
| 4 | Lack of investment in research and development for SMEs, especially for the combined use of digital technologies | | Project call to stimulate ecosystem building among SMEs and larger firms and the upscaling and implementation of digital technologies |
| 5 | Lack of investment to support the implementation of digital technologies by the construction industry | | Increasing the involvement of industrial partners via:<br>a. The campaign with best practices<br>b. The setup of Digital Innovation Hubs |
| 6 | Lack of trained employees (blue-collars) on the use of digital technologies | Skills & human resources | Provide lifelong (Digital) skills development for (blue collars) within the construction sector |
| 7 | Lack of experts for data handling and analysis | | Provide a multidisciplinary education program involving mathematics, computer-science, as well as the specific knowledge of the particular subject (e.g. manufacturing, material properties, building physics, etc.). |
| 8 | Lack of complementing ALIM standards | Facilitating policies & boundary conditions | Alignment of existing asset life-cycle information (ALIM) standards relevant for construction. |
| 9 | Lack of software (both open source and commercial off-the-shelf) that uses the available asset life-cycle information management standards. | | Design and develop software based on an optimal combined set of standards for ALIM. |
| 10 | Lack of data security and preparedness for cyber-attacks, especially in the construction sector. | | ICT firms and cyber security experts need to test and experiment with cybersecurity issues to come with solutions for data protection for construction companies. |

## ANNEX G: EXISTING INITIATIVES, EC ACTIONS, NATIONAL INITIATIVES AND TECHNICAL COMMITTEES

- UK: https://www.cdbb.cam.ac.uk/news/2018NovADNWelcomesTCA .
- Germany: https://d-twin.eu/en/research-project/
- Belgium: http://www.bimportal.be/nl
- France: http://www.cstb.fr/rapport-activite/2016/en/articles/scientific/psci-numerique.php
- The Netherlands: https://www.digidealgo.nl/
- BIMthinkspace: https://www.bimthinkspace.com/
- CoBuilder: https://cobuilder.com/en
- Knowledge transfer led by TNO from EU FP projects to SMEs in construction through regional business clusters with support from the Chamber of Commerce
- The TNO BIM QuickScan for SME (www.bimquickscan.nl)
- Easy-to-use online comparison tool to get a quick insight into various BIM software and other digital instruments; example in the Netherlands: http://www.vergelijkbimsoftware.nl/
- Action plan by TNO for digitisation Industry 4.0 in NL: Dutch Digital Delta (https://www.dutchdigitaldelta.nl/en/actionplan)
- Roadmap for BIM socialisation, standardisation and implementation for public authorities in Europe (V-Con: Virtual Construction) led by TNO and involving DEMO
- Data Privacy by Design' principles in NL Top Sector Innovation project OPSCHALER involving DEMO.
- https://www.digitaleurope.org
- European Association of Craft, Small and Medium-sized Enterprises
- EU BIM Task Group
- Connect & Construct project
- Top Sector Innovation Project: Data driven integrated growing systems https://www.tno.nl/en/focus-areas/buildings-infrastructure-maritime/roadmaps/buildings-infrastructure/greenhouse-design/data-driven-integrated-growing-systems/
- INNOVance Italian research project, that focused on the BIM Database for Construction Process Management
- Building Smart Finland. Building Smart Finland is a collaboration forum founded by Finnish Property Owners, A/E Consultantts, Software Vendors and Construction Companies.

## ANNEX H: RELEVANT EUROPEAN AND GLOBAL EXISTING STANDARDISATION ACTIVITIES

List with the most relevant European and Global existing standardisation activities[105] in the field of asset life-cycle information management/modelling covering areas BIM, GIS, Systems Engineering (SE), Monitoring & Control (M&C), IoT en Linked Data/Semantic Web (LD/SW).

- **W3C Linked Building Data (LBD) Community Group (CG)**
  - All basic linked Data/Semantic Web technology standards (RDF, SKOS, RDFS, OWL, SPARQL, Turtle, JSON-LD,….)
  - Domain ontologies like Semantic Sensor Networks (SSN), TIME, PROD, PROP, OPM, BOT, PROV, …)
- **buildingSmart International (bSI) Linked Data Working Group (LDWG)**
  - Industry Foundation Classes (IFC), ifcOWL
  - Property Set Definition (PSD) & standard Property Sets
  - buildingSmart Data Dictionary (bSDD)
- **Open Geo-spatial Consortium (OGC) (GIS standardisation on international level)**
  - CityGML
  - InfraGML
  - GeoSPARQL
- **CEN TC442 WG4 TG3 (BIM standardisation on EU level)**
  - Modelling & Linking Guide (MLG)
  - Product Data Templates (from other TGs in LD/SW)
  - EUROTL (from CEDR INTERLINK project)
- **ISO TC59/SC4 (BIM standardisation on international level)**
  - ISO Standard for the Exchange of Product model data (STEP) incl. EXPRESS, SPFF (used for IFC)
  - ISO 12006-2 & ISO 12006-3 (currently used as language for bSI bSDD)
  - Information Container Data Drop (ICDD) (ongoing we push MLG here too)
- **EU INSPIRE (GIS standardisation on EU level esp. transport/infra networks)**

[105] This list is based on the discussions with experts

## ANNEX I: POTENTIAL TOPICS TO WORK ON WITHIN THE CALL FOR DIHs

**Detailed Content Topics (**EC priorities in **bold)**

In general: Digitalisation in Construction / Built Environment for **Digital Transformation & Interoperability**

- Asset Life-cycle Management Process Modelling
- Relevant Key Performance Indicators (KPIs) detailing/quantifying
- Role of Asset Life-cycle Information Management
- Parametric product/materials development/standardisation
- Emerging Building Technologies (sensors, drones, robotics, 3D Scanners, 3D Printers, VR/AR)
- Development, Promotion, Training for and Implementation of a European Vision, Strategy and Roadmap for future-proof Asset Life-cycle Information Management, covering in an integrated way sub-topics/areas like:
  - Data-driven, risk-based asset maintenance/end-of-asset-life DSS
  - Building Information Modelling – BIM
  - Geospatial Information Systems – GIS
  - Systems Engineering – SE (incl. Life-cycle views & asset requirements)
  - Vendor Product Catalogues (assets, systems, component, materials)
  - Monitoring & Control including Big Data Analytics – IOT
  - Knowledge Engineering/Modelling, Knowledge Models
  - Including first principles, KPIs, levels of capability, maturity levels, use case types, business models.
- Formulation of a Modelling and Linking Guide enabling a simple but powerful asset modelling approach. Including the choice of modelling languages, guidelines of identification, naming, decomposing, specializing and especially ways to link all asset data sources together.

- Definition of a common ALIM asset modelling approach based involving existing international open standards like
  - the Industry Foundation Classes (IFC) and the buildingSmart Data Dictionary (bSDD) from buildingSmart International (bSI),
  - GML, CityGML and InfraGML from the Open Geospatial Consortium (OGC) and relevant CEN & ISO standards and the various ontologies currently under development in Europe.,
  - W3C standards like for semantic sensor networks (SSN)
  - European directives like INSPIRE for transport networks,
  - Key role for W3C web-based, semantic data technologies like Linked Data and Semantic Web via the Modelling and Linking Guide of 2. Gluing all above together as **latest next-gen deploying technology** for enabling the so needed **shared data spaces & libraries.**
- ALIM Software development (applications, apps, bots; all as OSS or COTS,)
  - Design Configurators & Verifiers
  - Regulation Checkers
  - Optimisation (incl. Near-optimal like genetic algorithms)

        - Data Analytics (including Bayesian networks)
        - **Artificial Intelligence (AI) including Machine Learning (ML)**
        - Expert Analyses: circularity, energy performance, structural analysis,
        - Semantic Data/Knowledge & Software Platforms
        - Data/Knowledge Interfaces (translators/convertors/APIs/QLs)
    - All executed in a **high-performance computing environment** and digital connectivity via **5G roll-out.**
    - Developing a European level reference knowledge/data centre applying 1-to-5 on a variety of European asset knowledge & data (roads, rails, buildings, bridges, tunnels, public spaces, large installations) combined with environmental and usage data. All linked together to form the input to a variety of data analytics/AI applications for diagnosis and planning purposes.
- Human Capital
    - Knowledge Management/Modelling (complementing data aspects above) on assets in their environment
    - Training & Courses for "**advanced digital skills**"
    - (**Cyber) Security & Trust**, Privacy, Authentication, Authorisation, Blockchain
    - **Connecting Communities**

## ANNEX J: COMPARABLE INITIATIVES FOR ACTION III

| Name | **Summary** | **Budget** | **Duration** |
|---|---|---|---|
| Luxembourg - Pillar I | LuxBuild2020 prepares Luxemburg's building sector in general and especially the blue collar workers for the EU 20-20-20 targets by developing a qualification **roadmap** for craftsmen.<br>The roadmap will focus on how to build up sustainably skills how to face the workforce shortage in the building sector. | € 300.000 (EU contribution 90 %) | June 2012 – December 2013 |
| LuxBuild - Pillar II | The project targets the **implementation** of the national roadmap for the qualification of craftsmen until 2020, through the development of training schemes and by promoting a mind-change among companies of the building sector. | € 671.802 (EU contribution 75%) | June 2012 – December 2013 |
| Skills Blueprint for the Construction Industry | The project proposes a new sectorial strategic approach to cooperate on skills in the construction industry and will support a better matching between skill needs of companies and skills provided by training centres. | € 3.999.665 | January 2019 - December 2022 |
| BUILD UP Skills Netherlands At Work | The main objective of BUS_N@W was to reach cooperation between the most important actors and stakeholders in order to complete the schemes for post-initial training, based on the BUILD UP Skills Pillar I project, and to unlock the available courses and training courses for the workforce in the Netherlands | € 602.096 (EU contribution 75%) | January 2013 - September 2015 |

## ACKNOWLEDGEMENTS

This report was supported by a number of our colleagues. In particular, we want to thank Ghazal Etminan, Jan Peters-Anders (both AIT), William Keeling (Trinomics) and Maurits Butter, Michel Bohms, Esra Bektas (all TNO) for their input.