**EMERGING TECHNOLOGIES**

This section presents the results of the citation analysis of the documents presented in Table 4.3. The documental analysis identified relatable themes, and others that have been reconverted in light of Industry 4.0, such is the case of embedded systems and cyber-physical systems (CPS). All of these technologies will be discussed during focus group discussion to determine the level of importance and maturity. A roadmap with technology and timeline will be developed at the end of study.

**Table 3.2.** Benchmarking Analysis for Technology

| Technology | Reference | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Smart dust |  |  |  |  |  |  | / |  |  |  |
| 4D Printing |  |  |  |  |  |  | / |  |  |  |
| Artificial general intelligence |  |  | / |  |  |  | / |  | / |  |
| Deep reinforcement learning |  |  |  |  |  |  | / |  |  |  |
| Neuromorphic hardware |  |  |  |  |  |  | / |  |  |  |
| Human Augmentation |  |  |  |  |  |  | / |  |  |  |
| 5G |  |  |  |  | / |  | / |  |  |  |
| Serverless PaaS |  |  |  |  |  |  | / |  |  |  |
| Digital twin |  |  |  |  |  |  | / |  |  |  |
| Quantum Computing |  |  |  | / |  |  | / |  |  |  |
| Volumetric Displays |  |  |  |  |  |  | / |  |  |  |
| Brain-Computer Interface |  |  |  |  |  |  | / |  |  |  |
| Conversational User Interface |  |  |  |  |  |  | / |  |  |  |
| Smart Workspace |  |  |  |  |  |  | / |  |  |  |
| Augmented Data Discovery |  |  |  |  |  |  | / |  |  |  |
| Edge Computing |  |  |  |  |  |  | / |  |  |  |
| Smart Robots | / |  |  | / | / | / | / | / | / | / |
| IoT Platform | / |  |  |  | / |  | / | / | / | / |
| Virtual Assisstants |  |  |  |  |  |  | / |  |  |  |
| Connected Home |  |  |  |  |  |  | / |  |  |  |
| Deep Learning |  |  |  |  |  |  | / |  |  |  |
| Machine Learning |  |  |  |  |  |  | / |  |  |  |
| Autonomous Vehicles |  |  | / | / | / |  | / |  |  |  |
| Nanotube Electronics |  |  |  |  |  |  | / |  |  |  |
| Cognitive Computing |  |  |  |  |  |  | / |  |  |  |
| Blockchain |  |  |  |  |  |  | / |  | / |  |
| Commercial UAVs (Drones) |  |  |  |  |  |  | / |  | / |  |
| Cognitive Expert Advisors |  |  |  |  |  |  | / |  |  |  |
| Enterprise Taxonomy and Ontology Management |  |  |  |  |  |  | / |  |  |  |
| Software-Defined Security |  |  |  |  |  |  | / |  |  |  |
| Augmented Reality |  |  |  |  |  |  | / | / | / |  |
| Virtual Reality |  |  |  |  | / |  | / | / | / |  |
| BIM |  |  |  | / | / |  | / | / |  |  |
| RFID |  |  |  | / |  |  | / | / |  |  |
| Telemetry Spines Integrated |  |  |  | / |  |  | / |  |  |  |
| Self-Assembly |  | / |  | / |  |  | / |  |  |  |
| 3D Printing |  | / |  | / |  |  | / | / | / | / |
| Self-Procuring |  |  |  | / |  |  | / |  |  |  |
| Self-healing materials |  |  |  | / |  |  | / |  |  |  |
| Autonomous plants and remote operations |  |  | / |  |  |  | / |  |  |  |
| Big data |  |  | / |  | / | / | / | / |  |  |
| Human-Machine Interfaces |  |  | / |  |  |  | / | / |  |  |
| Machine-to-machine communications |  |  | / |  |  |  | / |  |  |  |
| Cyber security |  |  | / |  |  |  | / |  |  |  |
| Medical Technology and Devices |  |  |  |  |  |  | / |  |  |  |
| Multi-functional Materials |  |  |  |  |  |  | / |  |  |  |
| Cyber-physical systems (CPS) embedded systems | / |  |  |  | / |  |  | / |  | / |
| Prefabrication |  |  |  |  |  |  |  | / |  |  |
| Modularization |  |  |  |  |  |  |  | / |  | / |
| Automation |  |  |  |  |  |  |  | / |  |  |
| Internet of services |  |  |  |  |  |  |  | / |  |  |
| Product-lifecycle management (PLM) |  |  |  |  |  |  |  | / |  |  |
| Mobile computing |  |  |  |  |  |  |  | / |  |  |
| Social media |  |  |  |  |  |  |  | / |  |  |
| Cloud computing |  |  |  |  |  |  |  | / |  | / |
| Photonics‑based materials processing technologies |  | / |  |  |  |  |  |  |  |  |
| Shaping technology |  | / |  |  |  |  |  |  |  |  |
| Non‑destructive examination technologies |  | / |  |  |  |  |  |  |  |  |
| Flexible sheet‑to‑sheet (S2S) and roll‑to‑roll (R2R) |  | / |  |  |  |  |  |  |  |  |
| Control technologies |  | / |  |  |  |  |  |  |  |  |
| Cognition‑based intelligent features |  | / |  |  |  |  |  |  |  |  |
| Advanced machine interaction with humans through ubiquity of mobile devices |  | / |  |  |  |  |  |  |  |  |
| Continuous monitoring |  | / |  |  |  |  |  |  |  |  |
| Intelligent machinery components and architectures |  | / |  |  |  |  |  |  |  |  |
| Energy technologies |  | / |  |  |  |  |  |  |  |  |
| Collaborative supply network |  | / |  |  |  |  |  |  |  |  |
| Connectivity |  | / |  |  |  |  |  |  |  | / |
| Mobility |  | / |  |  |  |  |  |  |  |  |
| Advanced material |  |  |  |  |  |  |  |  | / |  |
| Advanced sensor | / |  |  |  |  |  |  |  | / | / |
| Mixed reality |  |  |  |  |  |  |  |  | / |  |
| Bioengineering |  |  |  |  |  |  |  |  | / |  |
| Virtuality |  |  |  |  |  |  |  |  |  | / |
| Real Time Analysis and decision making |  |  |  |  |  |  |  |  |  | / |
| Decentralization |  |  |  |  |  |  |  |  |  | / |
| Service orientation |  |  |  |  |  |  |  |  |  | / |

1: Germany Industrie 4.0 (2011) 2: Factories of The Future (2013); 3: European Roadmap for Industrial Process Automation (2018) 4: A Roadmap for Industry in Mexico (2016); 5: Made in China (2018); 6: Taiwan Productivity 4.0 (2015); 7: BMS Smart Industry Research Roadmap (2018); 8: (Osunsanmi et al., 2018); 9: Pwc (2017); 10: (Santos et al., 2017)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Technology | Reference | | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Smart dust | / |  |  |  |  |  |  |  |
| 4D Printing | / |  |  |  |  |  |  |  |
| Artificial general intelligence | / |  | / |  |  |  | / |  |
| Deep reinforcement learning | / |  |  |  |  |  |  |  |
| Neuromorphic hardware | / |  |  |  |  |  |  |  |
| Human Augmentation | / |  |  |  |  |  |  |  |
| 5G | / |  |  |  |  |  |  |  |
| Serverless PaaS | / |  |  |  |  |  |  |  |
| Digital twin | / |  |  |  |  |  |  |  |
| Quantum Computing | / | / |  |  |  |  |  |  |
| Volumetric Displays | / |  |  |  |  |  |  |  |
| Brain-Computer Interface | / |  |  |  |  |  |  |  |
| Conversational User Interface | / |  |  |  |  |  |  |  |
| Smart Workspace | / |  |  |  |  |  |  |  |
| Augmented Data Discovery | / |  |  |  |  |  |  |  |
| Edge Computing | / |  |  |  |  |  |  |  |
| Smart Robots | / | / |  | / |  | / | / | / |
| IoT Platform | / |  |  | / |  | / | / | / |
| Virtual Assisstants | / |  |  |  |  |  |  |  |
| Connected Home | / |  |  |  |  |  |  |  |
| Deep Learning | / |  |  |  |  |  |  |  |
| Machine Learning | / |  |  |  |  |  |  |  |
| Autonomous Vehicles | / | / | / | / |  |  |  |  |
| Nanotube Electronics | / |  |  |  |  |  |  |  |
| Cognitive Computing | / |  |  |  |  |  |  |  |
| Blockchain | / |  |  |  |  |  | / |  |
| Commercial UAVs (Drones) | / |  |  | / |  |  | / |  |
| Cognitive Expert Advisors | / |  |  |  |  |  |  |  |
| Enterprise Taxonomy and Ontology Management | / |  |  |  |  |  |  |  |
| Software-Defined Security | / |  |  |  |  |  |  |  |
| Augmented Reality | / |  |  |  |  | / | / |  |
| Virtual Reality | / |  |  |  |  | / | / |  |
| BIM | / | / |  |  |  | / |  |  |
| RFID | / | / |  |  |  | / |  |  |
| Telemetry Spines Integrated | / | / |  |  |  |  |  |  |
| Self-Assembly | / | / |  |  | / |  |  |  |
| 3D  Printing | / | / |  | / | / | / | / | / |
| Self-Procuring | / | / |  |  |  |  |  |  |
| Self-healing materials | / | / |  |  |  |  |  |  |
| Autonomous plants and remote operations | / |  | / |  |  |  |  |  |
| Big data | / |  | / | / |  | / |  |  |
| Human-Machine Interfaces | / |  | / |  |  | / |  |  |
| machine-to-machine communications | / |  | / |  |  |  |  |  |
| Cyber security | / |  | / |  |  |  |  |  |
| Medical Technology and Devices | / |  |  | / |  |  |  |  |
| Multi-functional Materials | / |  |  |  |  |  |  |  |
| Cyber-physical systems (CPS) embedded systems |  |  |  | / |  | / |  | / |
| Prefabrication |  |  |  |  |  | / |  |  |
| Modularization |  |  |  |  |  | / |  | / |
| Automation |  |  |  |  |  | / |  |  |
| Internet of services |  |  |  |  |  | / |  |  |
| Product-lifecycle management (PLM) |  |  |  |  |  | / |  |  |
| Mobile computing |  |  |  |  |  | / |  |  |
| Social media |  |  |  |  |  | / |  |  |
| Cloud computing |  |  |  |  |  | / |  | / |
| Photonics‑based materials processing technologies |  |  |  |  | / |  |  |  |
| Shaping technology |  |  |  |  | / |  |  |  |
| non‑destructive  examination technologies |  |  |  |  | / |  |  |  |
| flexible sheet‑to‑sheet (S2S) and roll‑to‑roll (R2R) |  |  |  |  | / |  |  |  |
| Control technologies |  |  |  |  | / |  |  |  |
| Cognition‑based intelligent features |  |  |  |  | / |  |  |  |
| Advanced machine interaction with humans through ubiquity of mobile devices |  |  |  |  | / |  |  |  |
| Continuous monitoring |  |  |  |  | / |  |  |  |
| Intelligent machinery components and architectures |  |  |  |  | / |  |  |  |
| Energy technologies |  |  |  |  | / |  |  |  |
| collaborative  supply networks, OEMs |  |  |  |  | / |  |  |  |
| Connectivity |  |  |  |  | / |  |  | / |
| Mobility |  |  |  |  | / |  |  |  |
| Advanced material |  |  |  |  |  |  | / |  |
| Advanced sensor |  |  |  |  |  |  | / | / |
| Mixed reality |  |  |  |  |  |  | / |  |
| Bioengineering |  |  |  |  |  |  | / |  |
| Virtuality |  |  |  |  |  |  |  | / |
| Real Time Analysis and decision making |  |  |  |  |  |  |  | / |
| Decentralization |  |  |  |  |  |  |  | / |
| Service orientation |  |  |  |  |  |  |  | / |

1: BMS Smart Industry Research Roadmap (2018); 2: Built Environment 2050 (2014); 3: European Roadmap For Industrial Process Automation (2018); 4: Future of Manufacturing Initiative (2017); 5: Factories of Future (2010); 6: Osunsanmi et al. (2018); 7: Pwc (2017); 8: Santos et al. (2017)

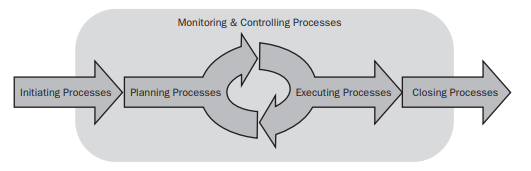
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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Technology | Reference | | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Smart dust | / |  |  |  |  |  |  |  |
| 4D Printing | / |  |  |  |  |  |  |  |
| Artificial general intelligence | / |  | / |  |  |  | / |  |
| Deep reinforcement learning | / |  |  |  |  |  |  |  |
| Neuromorphic hardware | / |  |  |  |  |  |  |  |
| Human Augmentation | / |  |  |  |  |  |  |  |
| 5G | / |  |  |  |  |  |  |  |
| Serverless PaaS | / |  |  |  |  |  |  |  |
| Digital twin | / |  |  |  |  |  |  |  |
| Quantum Computing | / | / |  |  |  |  |  |  |
| Volumetric Displays | / |  |  |  |  |  |  |  |
| Brain-Computer Interface | / |  |  |  |  |  |  |  |
| Conversational User Interface | / |  |  |  |  |  |  |  |
| Smart Workspace | / |  |  |  |  |  |  |  |
| Augmented Data Discovery | / |  |  |  |  |  |  |  |
| Edge Computing | / |  |  |  |  |  |  |  |
| Smart Robots | / | / |  | / |  | / | / | / |
| IoT Platform | / |  |  | / |  | / | / | / |
| Virtual Assisstants | / |  |  |  |  |  |  |  |
| Connected Home | / |  |  |  |  |  |  |  |
| Deep Learning | / |  |  |  |  |  |  |  |
| Machine Learning | / |  |  |  |  |  |  |  |
| Autonomous Vehicles | / | / | / | / |  |  |  |  |
| Nanotube Electronics | / |  |  |  |  |  |  |  |
| Cognitive Computing | / |  |  |  |  |  |  |  |
| Blockchain | / |  |  |  |  |  | / |  |
| Commercial UAVs (Drones) | / |  |  | / |  |  | / |  |
| Cognitive Expert Advisors | / |  |  |  |  |  |  |  |
| Enterprise Taxonomy and Ontology Management | / |  |  |  |  |  |  |  |
| Software-Defined Security | / |  |  |  |  |  |  |  |
| Augmented Reality | / |  |  |  |  | / | / |  |
| Virtual Reality | / |  |  |  |  | / | / |  |
| BIM | / | / |  |  |  | / |  |  |
| RFID | / | / |  |  |  | / |  |  |
| Telemetry Spines Integrated | / | / |  |  |  |  |  |  |
| Self-Assembly | / | / |  |  | / |  |  |  |
| 3D  Printing | / | / |  | / | / | / | / | / |
| Self-Procuring | / | / |  |  |  |  |  |  |
| Self-healing materials | / | / |  |  |  |  |  |  |
| Autonomous plants and remote operations | / |  | / |  |  |  |  |  |
| Big data | / |  | / | / |  | / |  |  |
| Human-Machine Interfaces | / |  | / |  |  | / |  |  |
| machine-to-machine communications | / |  | / |  |  |  |  |  |
| Cyber security | / |  | / |  |  |  |  |  |
| Medical Technology and Devices | / |  |  | / |  |  |  |  |
| Multi-functional Materials | / |  |  |  |  |  |  |  |
| Cyber-physical systems (CPS) embedded systems |  |  |  | / |  | / |  | / |
| Prefabrication |  |  |  |  |  | / |  |  |
| Modularization |  |  |  |  |  | / |  | / |
| Automation |  |  |  |  |  | / |  |  |
| Internet of services |  |  |  |  |  | / |  |  |
| Product-lifecycle management (PLM) |  |  |  |  |  | / |  |  |
| Mobile computing |  |  |  |  |  | / |  |  |
| Social media |  |  |  |  |  | / |  |  |
| Cloud computing |  |  |  |  |  | / |  | / |
| Photonics‑based materials processing technologies |  |  |  |  | / |  |  |  |
| Shaping technology |  |  |  |  | / |  |  |  |
| non‑destructive  examination technologies |  |  |  |  | / |  |  |  |
| flexible sheet‑to‑sheet (S2S) and roll‑to‑roll (R2R) |  |  |  |  | / |  |  |  |
| Control technologies |  |  |  |  | / |  |  |  |
| Cognition‑based intelligent features |  |  |  |  | / |  |  |  |
| Advanced machine interaction with humans through ubiquity of mobile devices |  |  |  |  | / |  |  |  |
| Continuous monitoring |  |  |  |  | / |  |  |  |
| Intelligent machinery components and architectures |  |  |  |  | / |  |  |  |
| Energy technologies |  |  |  |  | / |  |  |  |
| collaborative  supply networks, OEMs |  |  |  |  | / |  |  |  |
| Connectivity |  |  |  |  | / |  |  | / |
| Mobility |  |  |  |  | / |  |  |  |
| Advanced material |  |  |  |  |  |  | / |  |
| Advanced sensor |  |  |  |  |  |  | / | / |
| Mixed reality |  |  |  |  |  |  | / |  |
| Bioengineering |  |  |  |  |  |  | / |  |
| Virtuality |  |  |  |  |  |  |  | / |
| Real Time Analysis and decision making |  |  |  |  |  |  |  | / |
| Decentralization |  |  |  |  |  |  |  | / |
| Service orientation |  |  |  |  |  |  |  | / |

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Many of these technologies have been around or under development for several years. However, the interaction and resulting convergence of these technologies is creating an unprecedented pace and breadth of impact. Completely new industries may be created at these intersections. Thus, these are loosely termed as Industry 4.0 technologies.

**CLUSTERING**

Due to the specific characteristics of the construction industry as well as the complex nature of the construction projects, the key features of the Industry 4.0 concept are presented as 3 clusters with-in the value chain model: In large-scale construction projects, there might be hundreds of different project participants involved. Thus, the use of Industry 4.0 technologies from cluster 1, cluster 2 and cluster 3 can help to create a suitable construction environment for enhanced collaboration and communication. Figure 3.1 summarized the clustering of industry 4.0 technologies according to life cycle management.



**End-to-end digital integration of engineering across the entire value chain**

**Smart Construction (C3)**

-CPS

-RFID

-IoT

-Automation

-Modularization

3D Printing

Sensor

Robotic

**Simulation and modelling (C2)**

-Simulation tools/models

-BIM

-AR/VR/MR

**Digitlization and Virtualization (C3)**

-Cloud computing

-Big data

-Mobile computing

-Social media

-Digitlization

Figure 3.1: Cluster of Industry 4.0 technologies on the construction value chain by (Sarvari et al., 2018)