Mastering the skills of Construction 4.0: a review of the literature using science mapping

Senuri Siriwardhana
Department of Civil Engineering, Monash University, Melbourne, Australia, and
Robert Moehler
Department of Civil Engineering, Monash University, Melbourne, Australia and
Department of Infrastructure Engineering, The University of Melbourne, Melbourne, Australia

Abstract

Purpose – Skills development among construction stakeholders has become an increasingly urgent necessity for the successful implementation of Construction 4.0 in recent years. There is a lack of comprehensive analysis on the domain of Construction 4.0 implementation, with a focus on skills development. This study aims to address this gap through the use of the science mapping approach to show the gaps of research domain and propose future directions.

Design/methodology/approach – This study adopted a three-step holistic review approach, comprising bibliometric review, scientometric analysis, and qualitative discussion, to obtain a comprehensive overview of research in the field of Construction 4.0 skills development. On a total of 57 articles published in three databases, the influential sources, keywords, scholars, and articles in the domain were analysed. A follow-up discussion aimed to identify main-stream research topics, research gaps, and future research directions.

Findings – Findings discovered that the topics were concerned about Construction 4.0 whilst skills development aspect was lacking in creation of policies, frameworks, strategies in different contexts. The study revealed research gaps such as presence of skills gaps and shortages in some countries, the lack of frameworks and roadmaps for successful Construction 4.0 implementation, and the lack of readiness assessments from professional, company and industry viewpoints.

Originality/value – This study contributes to the knowledge in the domain of Construction 4.0 and the contribution of skills development for its implementation and a comprehensive overview with research gaps and future research directions in the domain.

Keywords Construction 4.0, Skills development, Science mapping

Paper type Literature review

1. Introduction

The construction industry plays a significant role in the global economy and is expected to continue to grow, despite challenging low levels of productivity (Hossain and Nadeem, 2019; You and Feng, 2020). According to Oesterreich and Teuteberg (2016), this can be attributed to complexity, uncertainty, a fragmented supply chain, short-term thinking, and the culture in the industry. To address these issues and improve performance in the construction industry, Industry 4.0, also known as the Fourth Industrial Revolution, has been introduced (Adabre and Chan, 2019; Moshood et al., 2020).

The term “Industry 4.0” has been widely used to describe the use of technology to enable to share information autonomously along the value chain in the co-production of goods and services with both human and non-human actors (Akyazi et al., 2020a, b; Karacay, 2018). While initially applied to the manufacturing industry, this concept has since been adopted by the Construction Industry (Perrier et al., 2020), which has its own version known as Construction 4.0. Construction 4.0 is characterized by closer collaboration across the
construction supply and value chain, supported by digital platforms to link the digital and physical layers of construction assets (Nagy et al., 2021). Sawhney and Riley (2020, p. 305) refined the definition of Construction 4.0 as, a paradigm that uses cyber-physical systems, and the Internet of Things, Data, and Services to link the digital layer consisting of Building Information Modelling (BIM) and Common Data Environment (CDE) and the physical layer consisting of the asset over its whole life to create an interconnected environment integrating organizations, processes, and information to efficiently design, construct and operate assets.

The integration of advanced digital technologies, including drones (Hilfert and König, 2016), 3D printing (Gerbert et al., 2016), 3D scanners, robotics, Radio Frequency Identification (RFID) into construction practices (Newman et al., 2021) transform tasks such as site inspection, building component production, and tracking of materials, equipment, and workers. Construction 4.0 (Oesterreich and Teuteberg, 2016) enables the use of robots and automated workflows, additive manufacturing, and prefabrication techniques. The shift from traditional construction methods can lead to costs savings and increase production efficiency (Dallasega et al., 2018; Suferi and Rahman, 2021). The use of additive manufacturing and prefabrication techniques can minimize coordination costs and material losses through the use of fixed sensors like RFID for the tracking of supplies (Moshood et al., 2020). Building Information Management (BIM) systems play a significant role by identifying potential issues during the design process by facilitating cooperation across organizational boundaries through the use of BIM-based programs and cloud or social media applications (Merschbrock and Munkvold, 2015; Wirtz and Rohrbeck, 2017; Dallasega et al., 2018; Moshood et al., 2020). The use of big data analytics and virtual reality technologies can improve health and safety in construction (Chun et al., 2012; Guo et al., 2013).

Despite its potential benefits, Construction 4.0 has not been fully adopted in the industry (Edwards et al., 2017; Osunsanmi et al., 2018; Al-Saeed et al., 2019; Suferi and Rahman, 2021). The cost of integrating advanced digital technologies has been perceived as a barrier (Chhetri et al., 2017; Edwards et al., 2019). Additionally, there are challenges in skills development to utilize these technologies effectively (European Construction Industry Federation (FCID), 2019; Ras et al., 2017); and a reluctance to disrupt traditional systems within the construction industry (Oesterreich and Teuteberg, 2016). Among these challenges, development of the necessary skills is the most significant for the successful implementation of Construction 4.0 (Edlund, 2019; Alaloul et al., 2018; European Construction Industry Federation (FCID), 2019; Newman et al., 2021; Ras et al., 2017).

The adoption of 4.0 technologies in the construction industry has brought about a need for skills development (Adepoju et al., 2021; Cerika and Maksumic, 2017). Additionally, the use of machines and robotic devices, coupled with interdisciplinary nature of the required skills, may also lead to shifts and upgrades to job profiles (Ras et al., 2017), resulting in skill shortages and skill gaps among the workforce (Adepoju and Aigbavboa, 2021; Al Amri et al., 2021; Alaloul et al., 2018; Bayraktar and Ataç, 2019). Owing to the unavailability of these new skills among current workforce, Construction 4.0 carries a greater risk of exacerbating skill shortages and widening the skill gap. Skill shortages occur when there is a lack of workers with the necessary skills in the labour market (Healy et al., 2011; Silva, 2018), while skill gaps occur when workers do not have the skills required for their current job (McGuinness and Ortiz, 2016). In order to mitigate these risks, it is crucial to have effective skills development strategies in place to produce construction personnel with the required skill sets related to Construction 4.0 technologies (Hamid and Rahim, 2022a, b).

The implementation of Construction 4.0 has placed a significant demand on skills development, but there is currently a lack of comprehensive analysis on this topic. While there have been multiple literature reviews on the concept (Klinc and Turk, 2019; Perrier et al., 2020; Sawhney et al., 2020), applications (Manzoor et al., 2021; Baduge et al., 2022), and challenges for Construction 4.0 (Nagy et al., 2021), these studies do not specifically address the major concern of skills and skills development in the Construction 4.0 era. This gap in research is crucial, as skill shortages and skill gaps could widen in the industry due to the
unavailability of new skills among the current workforce. Therefore, a structured systematic review is needed to address this gap and provide a comprehensive overview into skills-related discussions for the successful implementation of Construction 4.0. This study aims to address this gap through the use of the science mapping approach to answer the following research questions.

**RQ1.** What is the scientific landscape in the area of Construction 4.0 with specific reference to skills development including relationships and patterns between past research, authors and countries?

**RQ2.** What are the current research areas, existing research gaps, and future research directions in the domain of Construction 4.0 with reference to skills development?

The science mapping approach is a recent tool used to study the evolution of a research field and analyse its knowledge domain. This study uses the science mapping approach to present a map of scientific knowledge and demonstrate the development of scientific knowledge over time in the domain of Construction 4.0 with a focus on skills development. Additionally, this study employs a bibliometric research methodology to conduct a systematic review of the domain, identifying the most promising research areas, research gaps, and future research directions.

2. Research approach

This study deploys a systematic literature review using science mapping approach since it can outline trends in large sets of literature and bibliographical units (Cobo et al., 2013); cluster relational network connections between concepts that are difficult to systematically review in studies (Su and Lee, 2010) and extends into a qualitative discussion to develop a new research framework for future research (Jin et al., 2018; Xu et al., 2018). The combination of bibliometric analysis, scientometric analysis and qualitative discussion was adopted for the study. The research process is shown in Figure 1.

**Step 1- Bibliometric Search**

The bibliometric search was carried out in three main citation databases: Scopus, Web of Science and Engineering Village. Combining multiple databases, rather than relying on a single database, would yield more articles with acceptable and efficient coverage (Bramer et al., 2017; Zhao, 2014). The search string “Industry 4.0” OR “Construction 4.0” AND “Construction Industry” AND “Skill*” OR “Competence*” was used. Since the first article which discussed Construction 4.0 and skills development together appears in 2017 (Mechtcherine et al., 2018), the articles published in 2017–2022 in the English language were selected for the review. All articles were subjected to a title and abstract screening after removing duplicates.

**Step 2- Scientometric Analysis**

In this study, VOSviewer and Biblioshiny were chosen as scientific mapping tools. Biblioshiny’s interactive web interface allows user to perform relevant bibliometric and visual analyses, reducing information input intensity and usage threshold (Xie et al., 2020). VOSviewer enables distance-based bibliometric network visualization. Both tools were used to visualize, compute, and assess the impact of major publications, researchers, and countries on the Construction 4.0 skills development research community. The study also examined mainstream research keywords and their correlations.

**Step 3- Qualitative Discussion**

The qualitative discussion summarizes ongoing research topics, existing research gaps, and future research directions in Construction 4.0 with particular reference to skills development.
3. Results of scientometric analysis

Keyword-based bibliometric search selected 244 articles from all databases. The title screening screened out the articles on Industry 4.0 out of the construction sector. For example, Novak et al. (2019), Tonelli et al. (2016) and Gocev et al. (2020), focused on Industry 4.0 implementation in the manufacturing industry whereas French et al. (2018) focused on the aerospace industry which did not relate to the construction sector. Abstract screening selected the final literature sample that specifically addressed the skills development aspect of Construction 4.0. The final scientometric analysis included 57 articles.

3.1 An overview of the literature sample

Figure 2 shows the annual publication summary for the finalized literature sample (Construction 4.0 with reference to skills development). The graph demonstrates a gradual increase in publication since 2017. In 2017, studies of the domain remained in their infancy since the importance had not yet emphasized skills for Construction 4.0 success. In the next three years, the number of publications increased significantly, with an average of 10 publications annually. Therefore, we can consider 2017–2020 to be the period during which global scholars realized the importance of skills development for Construction 4.0. The number of publications reached its peak in 2020 with 16 publications. There was a slight decline in 2021 with 13 publications. However, 11 articles were published in the first six months of 2022, indicating that 2022 will be the most productive year for this domain.

3.1.1 Analysis of major research countries. The analysis of the countries that have contributed to publications in a particular field reveals the countries’ impact on that field (Xie et al., 2020). From 2017 to 2020, 35 countries produced articles on Construction 4.0 skills
development. Table 1 and Figure 3 show that the top 10 countries are three Asian (China, Malaysia, Singapore), one American (USA), four European (UK, Spain, Germany, Portugal), one African (South Africa), and one Oceania country (Australia).

Scholars from Malaysia and United Kingdom (UK) rank at the top in terms of the number of publications and total citations respectively. Malaysian researchers have specifically concentrated on Construction 4.0 education and training in construction institutes due to the lack of awareness and skills training availability in Malaysia (Ibrahim et al., 2019; Siti Rashidah et al., 2019; Hamid and Rahim, 2022a, b). The researchers also proposed a strategic readiness plan for the implementation of Construction 4.0 in Malaysia, as further described in Section 4.1 (Mansour et al., 2021). In the UK, the development of professional skills is of utmost importance, and technical skills for implementing Construction 4.0 technologies such as BIM, block chain, and cloud computing have been identified as priorities (Bolpagni et al., 2022). Among the soft skills, digital leadership and digital communication stand out (Bethan and Papadonikolaki, 2021). Scholars explored the Construction 4.0 readiness of different sectors

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of publications</th>
<th>Total citations</th>
<th>Average citations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malaysia</td>
<td>9</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>United Kingdom (UK)</td>
<td>7</td>
<td>56</td>
<td>8</td>
</tr>
<tr>
<td>Australia</td>
<td>7</td>
<td>34</td>
<td>5</td>
</tr>
<tr>
<td>South Africa</td>
<td>7</td>
<td>34</td>
<td>5</td>
</tr>
<tr>
<td>China</td>
<td>6</td>
<td>52</td>
<td>9</td>
</tr>
<tr>
<td>USA</td>
<td>4</td>
<td>49</td>
<td>12</td>
</tr>
<tr>
<td>Spain</td>
<td>4</td>
<td>18</td>
<td>5</td>
</tr>
<tr>
<td>Portugal</td>
<td>3</td>
<td>44</td>
<td>15</td>
</tr>
<tr>
<td>Singapore</td>
<td>2</td>
<td>25</td>
<td>13</td>
</tr>
<tr>
<td>Germany</td>
<td>2</td>
<td>6</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 1. Countries active in the domain

Source(s): Table created by Author

Figure 2. Annual publications from 2017 to 2022
in UK such as mega construction projects and off-site construction sector as described in subsection 4.2.3 (Taylor, 2017; Whitmore et al., 2020). Developed countries like Australia, South Africa and USA began their research in Construction 4.0 skills in earlier years. In Australia leadership skills were researched in the Construction 4.0 era (Yang et al., 2022) and scholars identified the necessity of governance, standards and regulations to succeed in Construction 4.0 (Smith and Sepasgozar, 2022). In South Africa, lack of skills, scalability risks and lack of clarity are the top three barriers while human resource development was identified as the suitable strategy (Akinradewo et al., 2022). USA focused on the evolution of new job roles with digital skills in the Construction 4.0 era (García de Soto et al., 2022).

The majority of publications are from Europe, indicating the greater adoption of Construction 4.0 technologies in Europe. Since Industry 4.0 originated in a European country (Germany), we can argue that most of its research and developments in many sectors have been concentrated in Europe. 70% of the top 10 countries are developed countries, while others such as China, Malaysia, and South Africa have positive economic development trends. This indicates that developed countries play a significant role in investigating the means of skills for the expansion of Construction 4.0 compared to developing countries. Construction 4.0 may be difficult to implement in developing countries due to insufficient budgets allocated for the adoption of new technologies, inadequate capital, the lack of popularity of Construction 4.0, and the absence of talent pools (Olatunde et al., 2022). The majority of the African region, certain European and Asian countries have not contributed to the domain, indicating that for some nations, concepts such as Construction 4.0 are entirely novel.

3.2 Network collaborations between countries

Figure 4 denotes the network collaboration between the countries. The minimum number of documents of a country was set as 1. As shown in Figure 4, the nodes of the network represent countries, while the edges between the nodes represent international cooperation. The thickness of an edge reflects how closely researches from different nations collaborate, while a country’s size indicates how frequently it collaborates.

As per Figure 4, there are seven primary clusters with different-coloured nodes. The UK and Spain, the second and third highest article producers, lead the collaborations. On the
contrary, Malaysia, which published the most articles in the domain, has only one international collaboration with Jordan, while the publications as single-country production were as high as 9. The collaboration between Malaysia and Jordan found that human capital, including intellectual agility, knowledge, skills, and competencies, was the most critical factor in the implementation of Construction 4.0 in both countries (Mansour et al., 2021). The UK had the strongest collaborations with Finland, Ireland, Netherlands, Portugal, South Africa, and Italy, and these collaborations focused on the role of construction professionals in Construction 4.0 and the features of the digital construction era (McHugh et al., 2020; Bolpagni et al., 2022) (as discussed in sub-section 4.1.1). Mexico and Romania collaborated on finding solutions for human skilling and the heterogeneous nature of projects and supply chains in the Construction 4.0 era by investigating collaborative networks and enterprise architecture views (Noran et al., 2020). Uruguay and Peru, in a collaboration led by Luna et al. (2019), proposed a new challenge-based learning course pack that incorporates serious games, gamification, and simulation to enhance Construction 4.0 skills for construction students in both countries. The rest of the research focused on independent studies, possibly due to significant differences in construction industries and Construction 4.0 frameworks between countries. However, future international collaborations must be developed to focus on skills development for Construction 4.0.

3.3 Co-occurrence of keywords
Keyword co-occurrence networks show statistical association between keywords as a network (Farooq, 2022). This can cluster research focuses based on keyword correlation strength to assess subject knowledge progress (Oladinrin et al., 2022). This study used VOSViewer based on “all keywords” and “Full counting” for the analysis. The minimum
occurrence of a keyword was set at 2. Some keywords with the same semantic meaning such as “Industry 4.0”, “Fourth Industrial Revolution” and “IR 4.0” were combined. Finally, 64 out of 528 terms met the criterion.

The node size is proportional to the number of publications that contain the term. Accordingly, the most studied keywords in the domain are Industry 4.0, Construction Industry, Construction 4.0, Digitalization and Skills. According to Figure 5, the cooccurrence of keywords is visualized under 6 clusters. Keywords within the same cluster generally have closer internal relationships. The keyword clusters can be described as follows.

1. **Emerging Construction 4.0 technologies (Green Cluster)** – Emerging technologies that represent the Construction 4.0 elements are highly linked with construction processes, construction projects and construction lifecycle. The implementation of digital twins and robotics for potential scenarios of construction processes was studied to improve workforce productivity and lifecycle management (Reinhardt et al., 2020; Akanmu et al., 2021). Construction automation applied in the industry, changed the whole life cycle of construction projects demanding different skill sets and readiness plans for the industry (Hamid and Rahim, 2022b; Ngo and Hwang, 2022).

2. **BIM as Construction 4.0 technology (Light Blue Cluster)** – BIM is playing a significant role in the digital transformation of the construction industry. BIM can convert traditional construction practices into modern technology (Urban et al., 2022). However, it has become difficult to successfully implement BIM due to the lack of BIM skilled talents in the industry (Ibrahim et al., 2019). This issue is addressed in Malaysia by identifying BIM skills for Construction 4.0 (Ibrahim et al., 2019); proposing digital transformation processes for construction projects that provide
strategies for human resource management (Hussain et al., 2020), investigating the readiness and challenges for skills training in construction training institutions (Hamid and Rahim, 2022b).

(3) **Construction 4.0 workforce (Red Cluster)** – In this cluster, establishing a Construction 4.0-friendly workforce through education and training is widely discussed. Construction 4.0 implementation has been researched using Augmented Reality (AR) and Virtual Reality (VR) in engineering education (Chan et al., 2021). The adaptation of Construction 4.0 through modifying mindsets and the development of expertise is investigated using different research approaches such as surveys (Aghimien et al., 2022, b; Alade and Windapo, 2020) and case studies (Bakri et al., 2022; Ngo and Hwang, 2022; Urban et al., 2022). Customized SERVQUAL models (refer sub section 4.1.1) were designed to assess the quality of Construction 4.0 education for graduates (Low et al., 2021) and vocational training (Kononiuk and Gudanowska, 2021).

(4) **Human factor in Construction 4.0 (Yellow Cluster)** – Human factor is co-studied with different aspects such as skills, awareness, health and safety in Construction 4.0 context. Skills and awareness development among construction employees under different conditions such as global health emergencies and climate changes was studied and identified the necessity of resource management, policy implementations, and education through virtual platforms (Akyazi et al., 2020a, b; Bolpagni et al., 2022; Mazurchenko and Zelenka, 2022). Health and safety can be achieved by integrating Construction 4.0 technologies such as big data, AR, VR for construction activities (Feng et al., 2022; Umeokafor et al., 2022). Challenges and opportunities to implement such technologies to improve health and safety in South Africa were also studied (Malomane et al., 2022).

(5) **Benefits of Construction 4.0 (Blue Cluster)** – Sustainability, enhanced collaboration, and industrial development are studied as the benefits of construction digitalization. Studies described how sustainability and industrial development can be achieved by identifying key skill areas of project managers (Al Amri et al., 2021) and civil engineers (Akyazi et al., 2020a, b) within the Construction 4.0 context. Professional sustainability was studied in Slovakia and revealed the need for vocational training and requalification (Grenčíková et al., 2021). John et al. (2021) studied how collaborations, not only within the built environment, but also between students and professionals, can be improved through the use of Construction 4.0 technologies to reach the desired productivity goals.

(6) **Management role in Construction 4.0 (Purple Cluster)** – Project management and risk management in Construction 4.0 environment are co-studied in this cluster. The impact of Construction 4.0 on project management skills and competencies (Ngo and Hwang, 2022); and risk management activities such as risk identification, risk assessment and accident prevention (Umeokafor et al., 2022) were studied.

3.4 **Co-authorship analysis**

Co-authorship analysis can provide the cooperation patterns between two or more authors (Glanzel and Schubert, 2005; Newman, 2004). Since the collaborations are limited in the domain, this study performed co-authorship analysis with a minimum of 1 publication and 2 citations per author. In total, 115 out of 212 authors met the criteria as per Figure 6.

As per Figure 6, there are two major clusters, representing the research network of two groups of scholars in the domain of Construction 4.0 with reference to skills development.
Accordingly, Feng Y. is the author who made the major collaborations in the field. Feng Y. has research expertise in sustainable procurement, construction safety, BIM and robotics in construction. However, out of 212 authors, only 15 authors contributed to the collaborations indicating the need to strengthen author collaborations in the production of publications on the adoption of Construction 4.0, with a focus on skill development.

More quantitative measurements of the scholars are listed in Table 2. According to Table 2, Anisimova T., Kalimullina O., Sabirova F., Shatunova O. are the most productive authors in the domain of Construction 4.0 with reference to skills development, with more total citations than other authors. These authors have research expertise in skills development, innovation management, sustainable development, teaching and learning.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Documents</th>
<th>Total citations</th>
<th>Avg. pub. Year</th>
<th>Avg. citations</th>
<th>Avg. norm. citations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anisimova T.</td>
<td>1</td>
<td>50</td>
<td>2019</td>
<td>50</td>
<td>3.28</td>
</tr>
<tr>
<td>Kalimullina O.</td>
<td>1</td>
<td>50</td>
<td>2019</td>
<td>50</td>
<td>3.28</td>
</tr>
<tr>
<td>Sabirova F.</td>
<td>1</td>
<td>50</td>
<td>2019</td>
<td>50</td>
<td>3.28</td>
</tr>
<tr>
<td>Shatunova O.</td>
<td>1</td>
<td>50</td>
<td>2019</td>
<td>50</td>
<td>3.28</td>
</tr>
<tr>
<td>Agustí-juan I.</td>
<td>1</td>
<td>36</td>
<td>2022</td>
<td>36</td>
<td>16.00</td>
</tr>
<tr>
<td>García De Soto B.</td>
<td>1</td>
<td>36</td>
<td>2022</td>
<td>36</td>
<td>16.00</td>
</tr>
<tr>
<td>Hunhevicz J.</td>
<td>1</td>
<td>36</td>
<td>2022</td>
<td>36</td>
<td>16.00</td>
</tr>
<tr>
<td>Joss S.</td>
<td>1</td>
<td>36</td>
<td>2022</td>
<td>36</td>
<td>16.00</td>
</tr>
<tr>
<td>Calvetti D.</td>
<td>1</td>
<td>23</td>
<td>2020</td>
<td>23</td>
<td>3.74</td>
</tr>
<tr>
<td>Gonçalves M.C.</td>
<td>1</td>
<td>23</td>
<td>2020</td>
<td>23</td>
<td>3.74</td>
</tr>
<tr>
<td>Meda P.</td>
<td>1</td>
<td>23</td>
<td>2020</td>
<td>23</td>
<td>3.74</td>
</tr>
<tr>
<td>Sousa H.</td>
<td>1</td>
<td>23</td>
<td>2020</td>
<td>23</td>
<td>3.74</td>
</tr>
<tr>
<td>Jassbi J.</td>
<td>1</td>
<td>17</td>
<td>2020</td>
<td>17</td>
<td>2.77</td>
</tr>
<tr>
<td>Ramezani J.</td>
<td>1</td>
<td>17</td>
<td>2020</td>
<td>17</td>
<td>2.77</td>
</tr>
<tr>
<td>Abawajy J.</td>
<td>1</td>
<td>16</td>
<td>2021</td>
<td>16</td>
<td>3.29</td>
</tr>
<tr>
<td>Al-ameri R.</td>
<td>1</td>
<td>16</td>
<td>2021</td>
<td>16</td>
<td>3.29</td>
</tr>
<tr>
<td>Edwards D.J.</td>
<td>1</td>
<td>16</td>
<td>2021</td>
<td>16</td>
<td>3.29</td>
</tr>
<tr>
<td>Ghosh A.</td>
<td>1</td>
<td>16</td>
<td>2021</td>
<td>16</td>
<td>3.29</td>
</tr>
<tr>
<td>Hosseini M.R.</td>
<td>1</td>
<td>16</td>
<td>2021</td>
<td>16</td>
<td>3.29</td>
</tr>
<tr>
<td>Thwala W.D.</td>
<td>2</td>
<td>16</td>
<td>2021</td>
<td>8</td>
<td>1.65</td>
</tr>
</tbody>
</table>

**Note(s):** Scholars in the Table are listed based on Total Citations

**Source(s):** Table created by Author
areas. The average publication year of authors reveals the emerging authors including Agusti-juan I., García De Soto B., Hunhevicz J., Joss S. whose publications are generally around 2022. The normalized citation analysis indicates the average yearly influence of authors (Jin et al., 2019). The same emerging authors with the expertise in Smart construction, Construction engineering and management, digitalization and automation, provide the highest yearly influence in the domain. However, the absence of authors with more than two articles in the domain is concerning since this shows the unpopularity on the domain among the authors which should be changed in the future.

3.5 Co-citation analysis
Co-citation analysis counts the number of documents that have cited any two documents. Among the classified levels of co-citation analysis (document, author, source), this study used the author co-citation analysis. The co-citation of authors results when a researcher cites any work of any given author along with the work of any other author in a new document (van Eck and Waltman, 2014). Figure 7 presents the author co-citation analysis for this study.

The size of each “node” on the co-citation map represents the relative frequency of author citations in reference lists, while the lines connecting author nodes represent “co-citations” of the two authors by other scholars. The “proximity” of nodes reveals the thematic similarity between the authors (Zupic and Cater, 2014). As per Figure 7, there are 3 clusters in the domain.

The largest cluster (red cluster) comprises authors with the highest total link strength such as Chan A.P.C., Hwang B.G., Lu W. most of whom have affiliations in Asia. These authors have been cited in studies focusing on Construction 4.0 implementation in different contexts such as project management (Ngo and Hwang, 2022), skills management (Ibrahim et al., 2019; Low et al., 2021) and construction process management (Atkinson et al., 2022; Ginigaddara et al., 2022). Two other clusters connected to cluster one, yet not as strongly. Teizer, J., Anumba C.J., and Li H. have high total link strength in cluster 2 (Green cluster). The authors in this cluster are cited in the studies related to Construction 4.0 workforce (García de Soto et al., 2022), Industry 4.0 technologies such as cyber-physical systems and BIM (Akanmu et al., 2021). A wide dispersion of authors in the physical space can be noted in the cluster 3 (blue cluster) compared to the other 2 clusters. This is because the cited studies covered multiple sectors and theoretical aspects with little thematic similarity. Wang X. and Xu M. are the major authors who have the highest total link strength in cluster 3. These authors are cited in the studies related to Construction 4.0 technology implementation such as augmented reality (Urban et al., 2022) and BIM (Ibrahim et al., 2019); skills readiness for Construction 4.0 (Shuhaimi et al., 2022).

Overall, Wang X. and Li H. with the most betweenness centrality link the most authors in all co-citation network clusters.
3.6 Document analysis

Setting the minimum citation number at 2 in filtering the literature sample, a total of 30 articles met the requirements. These most influenced articles in terms of total citations are listed in Table 3.

The study by García de Soto et al. (2022) focusing on the implications of Construction 4.0 for the workforce and organizational structures has received significantly higher normalized citations than the other articles. The change in organizational structures due to the emergence of new job roles with higher job variability which is a huge challenge for workers is discussed in the study. The article with the second-highest normalized citations materializes the main principles and behaviour of workers in a Construction 4.0 scenario (Calvetti et al., 2020). Ultimately, it presents a workforce productivity assessment model which can be used within Construction 4.0 environment. This suggests that these most influential articles generally discuss the construction workforce in the context of Construction 4.0. The article with the third highest normalized citations discussed on implementing cyber-physical systems and digital twins in the construction industry. This article highlights the potential scenarios that

<table>
<thead>
<tr>
<th>Document</th>
<th>Title</th>
<th>Total citations</th>
<th>Normalized citations</th>
</tr>
</thead>
<tbody>
<tr>
<td>García de Soto et al. (2022)</td>
<td>Implications of Construction 4.0 to the workforce and organizational structures</td>
<td>36</td>
<td>16.00</td>
</tr>
<tr>
<td>Calvetti et al. (2020)</td>
<td>Worker 4.0: The future of sensed construction sites</td>
<td>23</td>
<td>3.74</td>
</tr>
<tr>
<td>Akanmu et al. (2021)</td>
<td>Towards next generation cyber-physical systems and digital twins for construction</td>
<td>13</td>
<td>2.68</td>
</tr>
<tr>
<td>Low et al. (2021)</td>
<td>Future-ready project and facility management graduates in Singapore for Industry 4.0: Transforming mindsets and competencies</td>
<td>13</td>
<td>2.68</td>
</tr>
<tr>
<td>Hwang et al. (2022)</td>
<td>Challenges and Strategies for the Adoption of Smart Technologies in the Construction Industry: The Case of Singapore</td>
<td>12</td>
<td>5.33</td>
</tr>
<tr>
<td>Akyazi and Alvarez (2020a)</td>
<td>Skills needs of the civil engineering sector in the European Union countries: Current situation and future trends</td>
<td>12</td>
<td>1.95</td>
</tr>
<tr>
<td>Adepoju and Aigbavboa (2021)</td>
<td>Assessing knowledge and skills gap for Construction 4.0 in a developing economy</td>
<td>9</td>
<td>1.85</td>
</tr>
<tr>
<td>Alade and Windapo (2020)</td>
<td>Developing effective 4IR leadership framework for construction organizations</td>
<td>8</td>
<td>1.30</td>
</tr>
<tr>
<td>Mansour et al. (2021)</td>
<td>Implementing Industry 4.0 in the construction industry- strategic readiness perspective</td>
<td>5</td>
<td>1.03</td>
</tr>
<tr>
<td>Ghosh et al. (2021)</td>
<td>Real-time structural health monitoring for concrete beams: a cost-effective 'Industry 4.0' solution using piezo sensors</td>
<td>5</td>
<td>1.03</td>
</tr>
<tr>
<td>Hossain and Nadeem (2019)</td>
<td>The fourth industrial revolution and organizations' propensity towards building information modelling (BIM) adoption</td>
<td>5</td>
<td>0.33</td>
</tr>
<tr>
<td>Ginigaddara et al. (2022)</td>
<td>Development of an offsite construction typology: A delphi study</td>
<td>2</td>
<td>0.89</td>
</tr>
<tr>
<td>Bolpagni et al. (2022)</td>
<td>Shaping the Future of Construction Professionals</td>
<td>2</td>
<td>0.89</td>
</tr>
<tr>
<td>Al Amri et al. (2021)</td>
<td>Towards sustainable I4.0: Key skill areas for project managers in GCC construction industry</td>
<td>2</td>
<td>0.41</td>
</tr>
<tr>
<td>Rivera et al. (2021)</td>
<td>Proposal for the construction of innovation skills in engineering education in the context of Industry 4.0 and Sustainable Development Goals (SDGs)</td>
<td>2</td>
<td>0.41</td>
</tr>
</tbody>
</table>

Table 3. Most influenced articles in the domain

Source(s): Table created by Author
these Construction 4.0 technologies can be used to improve workforce productivity, health, and safety, lifecycle management of building systems, and workforce competency. The main themes of other articles include skills development in different construction professions for Construction 4.0 (Akyazi et al., 2020a, b; Low et al., 2021), Construction 4.0 implementation plans and frameworks (Alade and Windapo, 2020; Mansour et al., 2021); and Construction 4.0 in different sectors (Ghosh et al., 2021; Ginigaddara et al., 2022).

4. Qualitative discussion

The third stage of the study is a qualitative discussion of current research topics, research gaps, and future research directions. The discussion is as below.

4.1 Research topic within the domain

Due to rapid technological advancement in the construction industry, the evolution of skills has been discussed combined with different subject areas within construction and project management, civil and structural engineering and social sciences using different methodologies (see Table 4).

In addition, the key research concerns in the domain are discussed below.

4.1.1 Progress of Construction 4.0 implementation in different countries. The popularity of Construction 4.0 has led to several research and development projects in different countries. The progress of Construction 4.0 adoption has been studied in developed countries like UK, Italy, and Spain (Akyazi et al., 2020a, b; Atkinson et al., 2022) while some developing countries like Singapore, Malaysia, and India focused on the implementation capabilities (Singh and Misra, 2021; Hamid and Rahim, 2022a, b; Hwang et al., 2022). For example, Atkinson et al., 2022 found that UK construction firms deploy Construction 4.0 technologies alongside

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Description</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrative Reviews</td>
<td>Construction 4.0 impact to the workforce</td>
<td>Ibrahim et al. (2019) and Brucker Juricic et al. (2021)</td>
</tr>
<tr>
<td>Systematic Reviews</td>
<td>Construction 4.0 in management perspective Skills development and education for construction 4.0</td>
<td>Maskuryi et al. (2019)</td>
</tr>
<tr>
<td>Desk Studies</td>
<td>Construction 4.0 skills requirement for civil engineering sector</td>
<td>Agyemang and Fong (2019) and Zabidin et al. (2019)</td>
</tr>
<tr>
<td>Interviews</td>
<td>Challenges and Strategies for Construction 4.0 Skills for facilities managers in Construction 4.0</td>
<td>Hwang et al. (2022)</td>
</tr>
<tr>
<td>Surveys</td>
<td>Skills development for construction employees Impact of Construction 4.0 for project managers</td>
<td>Low et al. (2021)</td>
</tr>
<tr>
<td>Case Studies</td>
<td>Challenges for Construction 4.0 in infrastructure projects</td>
<td>Atkinson et al., 2022</td>
</tr>
<tr>
<td></td>
<td>Different roles in Construction 4.0 site (construction execution phase)</td>
<td>García de Soto et al. (2022)</td>
</tr>
<tr>
<td>Case Studies</td>
<td>Promotion of technologies for construction students</td>
<td>Urban et al. (2022)</td>
</tr>
<tr>
<td>Modelling</td>
<td>Model to evaluate the strategic readiness for Construction 4.0</td>
<td>Mansour et al. (2021)</td>
</tr>
<tr>
<td>Modelling</td>
<td>Model for skills transferring</td>
<td>Wang et al. (2020)</td>
</tr>
</tbody>
</table>

Source(s): Table created by Author

Table 4. Different methodologies used by the researchers
traditional methods. Singh and Misra (2021) developed a framework based on the Indian construction industry to accept Construction 4.0 technologies.

In addition, the studies have focused on different factors that affect the implementation of Construction 4.0 such as governmental support, economic stability, human resource awareness and skills adequacy. Hamid and Rahim (2022a, b) examined the awareness levels of construction skills training institutes and assessed a strategic plan to prepare the workforce for Construction 4.0 in Malaysia. Adepoju and Aigbavboa (2021) studied skills adequacy and economic stability to adopt Industry 4.0 based on the Nigerian construction industry in which the findings can be extrapolated to developing economies.

Blayone and Van Oostveen (2021) created a worker readiness model for Construction 4.0 that identified flexibility readiness, innovation readiness, inter-personal readiness, technology readiness, and inter-agent readiness as five dimensions that affect worker readiness in Canada. Mansour et al. (2021) examined strategic readiness for Construction 4.0 based on human capital, relationship capital and structural capital in Malaysia and Jordan. SERVQUAL model which is used to assess the SERVice QUALity or performance through 5 dimensions (Reliability, Assurance, Tangibles, Empathy, Responsiveness) was customized to assess the Construction 4.0 education in Poland (Kononiuk and Gudanowska, 2021); and vocational training in Singapore (Low et al., 2021).

4.1.2 Challenges for Construction 4.0 implementation in construction industry. Construction 4.0 adoption is still in its infancy; thus several studies have attempted to pinpoint its challenges in different perspectives. Singh and Misra (2021) identified the major challenges to Construction 4.0 implementation in the Indian construction industry as the high cost of technological establishment, absence of technically skilled workers, inadequate recognition of the potential benefits of Construction 4.0, insufficient government support in the form of legislations and laws, and so on. Similar research in Singapore found that data and information sharing, regulatory compliance, skills shortage, and stakeholder collaboration are the main obstacles. Al Amri et al. (2021) surveyed the UK construction sector and identified both intrinsic and extrinsic barriers to the application of Construction 4.0. According to this study, intrinsic barriers include a lack of required Industry 4.0 skills, a culture that is resistant to change, cyber security concerns, and a lack of investment capital, while extrinsic barriers include differences in data interoperability, quality, and volume, differences in technological maturity, and a lack of Construction 4.0 expertise.

Additionally, some studies focused on specific Construction 4.0 technologies and discovered implementation difficulties. For examples, low level of employee training and education, lack of expertise and experience transfer, lack of corresponding legislation for implementing Building Information Technology (BIM) (Mazurchenko and Zelenka, 2022); shortage of specialized workers, insufficient system and data security and high investment costs for implementing Artificial Intelligence (AI) (Cisterna et al., 2021); lack of skills and knowledge, markets risks, high energy consumption, the vulnerability of smart contracts and authorization issues for implementing block chain technology (Akinradewo et al., 2022) and; data security issues, data access restrictions, change resistance, distracted workers, skills and training issues for implementing Mobile Information and Communication Technology (M-ICT) (Atkinson et al., 2022) were identified as major challenges.

4.1.3 Human resource development for Industry 4.0 implementation in construction industry. Human resource development has been recognized as a critical factor for the success of Construction 4.0. However, Karimulla et al. (2020) discovered that human resource development in the context of Construction 4.0 is at a moderate level. In the same study, factors influencing human resource development were identified as Construction 4.0-related training, skills and knowledge exploitation, new Construction 4.0 skill development and organizational strategies. García de Soto et al. (2022), who investigated the impact of Construction 4.0 on the construction workforce, found that conventional construction and
Construction 4.0 technologies would often coexist, resulting in higher employment variability and new administrative and operations/execution positions. Acknowledging this, Bolpagni et al. (2022) introduced new job roles that can emerge in the construction industry such as process modeller, building change agent, interoperability programmer, benefits manager, user researcher, otologist, data regulator and data governance specialist. Bolpagni et al. (2022) further revealed the role of academia in shaping future construction professionals toward the Industry 4.0 era by presenting a curriculum guideline framework.

4.1.4 Skills development within the construction industry in Construction 4.0 era. Skills development among construction stakeholders has been a major topic of success in the implementation of Construction 4.0 in recent years. Several studies focused on the skills development of construction stakeholders who are currently employed in the sector, while others focused on construction students who would soon enter the industry.

Mazurchenko and Zelenka (2022) underlined the importance of digital skills development and found that employees’ reluctance to acquire new technologies and a lack of time to develop their abilities due to workload are the biggest hurdles. Rao and Yang (2018) researched skill development procedures among construction professionals and emphasized that multi-party collaborative skill training, cultivation of modern apprenticeship, and dual-creation ability can enhance skill development in a Construction 4.0 context. Some research has studied the roles of construction stakeholders in the Construction 4.0 era, with an emphasis on skill development. Al Amri et al. (2021), for instance, found that increased exposure and training within organizations fully prepares project managers for Industry 4.0 technologies. The study also found that project managers with academic and professional credentials were better prepared for Construction 4.0. Due to the dominant presence of Small and Medium-sized Enterprises (SMEs) in the construction industry, several studies have specifically focused on the impact of Construction 4.0 on these enterprises and recommended strategies for skills development that can be practically implemented (Aghimien et al., 2022a, b). For example, a study based on Polish SMEs discovered that recruiting new skilled staff, offering external employee training and outsourcing tasks to external contractors are the top three strategies to reduce Construction 4.0 skills gap (Mazurchenko and Zelenka, 2022). Hwang et al. (2022) also focused on SMEs and highlighted that training, sharing of success stories, development of standards, provision of incentives and partnerships can help SMEs to successfully implement Construction 4.0. These studies emphasize the need for tailored skills development strategies for SMEs to keep pace with the technological advancements brought by Construction 4.0.

Regarding the development of skills in the academic sector, Agyemang and Fong’s (2019) study on construction management students highlighted the importance of vocational education in schools and universities with Construction 4.0 technologies. In recognition of this, Zabidin et al. (2019) discussed Education 4.0 in construction engineering, which improves the connection between existing learning course content and Construction 4.0 elements including augmented reality, simulation and modelling, smart classroom, and an educational framework. The authors believe that Education 4.0 can boost students’ awareness and comprehension, demonstrating the significance of Construction 4.0.

4.2 Current research gaps within the domain of construction 4.0 implementation with particular reference to skill development

4.2.1 Skill gaps and skill shortages. Construction 4.0 is mainly hindered by skills gaps and shortages. According to the European Union (2019), more than one-third of European construction companies struggle to locate staff with the ability to use Construction 4.0 technologies. Another study related to the Czech construction industry shows that companies face a critical shortage of qualified labour, which is a key issue for the sector (Mazurchenko and Zelenka, 2022). Whilst most studies emphasized that existing skill sets do not meet Construction 4.0 standards (Karimulla et al.,
some studies have stressed where the actual skills gap exists. Accordingly, Adepoju and Aigbavboa (2021) elaborated that, there is a significant skills gap in human-machine communication, data analytics, and cyber security. Moreover, the Construction Industry Training Board (2018) identified skill gaps in data collection, communication, and management. To this end, Mazurchenko and Zelenka (2022) added that resolving skill gaps in data security, processing, analytics, and problem-solving in the digital environment requires construction stakeholders to use new change management approaches, cultural shifts, and technology to achieve successful digital transformation. Although the above studies have highlighted numerous skill gaps in the domain, there have not been sufficient investigations to determine the exact skills requirement for Construction 4.0. A systematic comparison between existing traditional skill sets and Construction 4.0 skill sets would enhance the research and practice worldwide. Furthermore, some studies have investigated Construction 4.0 skill sets focussing on particular professions such as industrial engineers (Sekhari et al., 2020); project managers (Al Amri et al., 2021) and facility managers (Low et al., 2021). Likewise, there is a necessity of investigating the Construction 4.0 skills sets required by the different stakeholders.

4.2.2 Impact of Construction 4.0 on construction stakeholders. Construction stakeholders are key to implementing Construction 4.0 since they are at the centre of these innovations. Al Amri et al. (2021) emphasized that although different Construction 4.0 technologies have been introduced, employee engagement is difficult to achieve. To this, Margherita and Braccini (2020) and Neumann et al. (2021) added that employees that are unmotivated, uninterested, or feel threatened by new technologies may reject Construction 4.0 and future advancements. Therefore, this issue should be carefully addressed if Construction 4.0 implementation needs to be successful. However, the impact of Construction 4.0 on construction stakeholders is not fully understood from the existing literature, making it imperative to assess all potential concerns and develop solutions (Al Amri et al., 2021). This is supported by Adepoju et al. (2021) and Low et al. (2021), who point out that the human aspect of Construction 4.0 implementation has been underrepresented in previous studies. Human factors can be further examined according to subgroups such as individuals, organizations, construction projects, and the nation as a whole. Blayone and Van Oostveen (2021) also emphasized the need for research to determine how to manage the mental and physical well-being of stakeholders to prepare them for the adoption of Construction 4.0 technologies.

4.2.3 Construction 4.0 implementation (readiness) in the construction industry. Although some studies have investigated the readiness of the construction sector to embrace Construction 4.0 (Whitmore et al., 2020; Blayone and Van Oostveen, 2021; Mansour et al., 2021), there are some gaps in the domain of readiness. Industry 4.0 technologies vary in readiness. For example, Oesterreich and Teuteberg (2016) reported that BIM and cloud computing have reached commercial maturity and are widely available, while augmented, virtual, and mixed reality are still under development. These readiness levels for each technology should be explored in terms of resource availability, financial availability, and human resource availability (Mazurchenko and Zelenka, 2022). Specifically, human resource readiness should be examined with skills readiness, mental readiness and cultural readiness. Further, empirical investigations are required to assess the readiness for Construction 4.0 in different enterprise levels such as small, medium and large enterprises.

4.2.4 The necessity of standard frameworks including skills frameworks. The rapid implementation of Construction 4.0 technologies is currently underway. While this provides the industry with a much-needed boost, it is concerning that the sector’s socio-technical frameworks have not been improved accordingly. Further, Lau et al. (2019) found that most Industry 4.0 roadmaps, frameworks, and strategic plans focused on manufacturing, not construction. This may weaken Construction 4.0 deployment unless existing frameworks are modified or new frameworks are established (McHugh et al., 2020). More specifically, Mazurchenko and Zelenka (2022) stressed that Construction 4.0 requires updated employee
skills frameworks. To this, Mansour et al. (2021) added that skills models or frameworks should be focused on specific technologies, construction stakeholders and construction processes. Further, there is a lack of studies on the development of policy frameworks for the implementation of Construction 4.0.

4.2.5 Skill development for Industry 4.0. Several studies have shown that the construction industry is not interested in the development of Construction 4.0 skills (Low et al., 2021; Mazurchenko and Zelenka, 2022; Zabidin et al., 2019). Skills development should focus on two target groups: construction stakeholders and construction students (such as undergraduates). Since the target groups are diverse, independent studies are required to develop strategies for skills development based on educational institutions and construction organizations.

4.3 Future research directions

Future research directions were outlined based on research gaps and existing research topics as below

(1) The development of reskilling and upskilling strategy plans has become a potential study direction with respect to various management levels and professional organizations for the effective implementation of Construction 4.0. Studies can be conducted to identify education curriculums that are compatible with Industry 4.0 era for construction students. Additionally, the features of training programmes for skills development should be investigated with regard to different organizational levels.

(2) It is necessary to develop regular frameworks and road maps to implement Construction 4.0 successfully. Among these are Construction 4.0 skills frameworks, skill development roadmaps, and skill management strategies.

(3) Since the construction industry is interdisciplinary, different participants have distinct roles and responsibilities in Construction 4.0, and the results may not reflect the unique needs of each job type. For example, in Construction 4.0 context, project developers may value different skill sets than contractors. There is also a need for tailored skills development strategies for SMEs to keep pace with the technological advancements brought by Construction 4.0. The interests and concerns of each party can thus affect the successful implementation of Construction 4.0. Thus, studies with larger, more representative samples are needed to identify Construction 4.0 skill sets and practises focussing on different construction stakeholders.

(4) Studies integrating different geographical contexts could raise more attention and lead to significant contributions to the research community. In different regions, Construction 4.0 technology adoption challenges, stakeholder readiness, and cultural and societal impact can be examined.

(5) Another research trend is studying on new job profiles and their skill sets in Construction 4.0 era. Since job profiles such as BIM manager, data regulator, and data governance specialist are not fully explored, their responsibilities in the effective implementation of Construction 4.0 must be investigated.

5. Conclusion

This study on Construction 4.0 adoption focussing on skills development aspects utilized a holistic approach incorporating a bibliometric literature review, scientometric analysis and qualitative discussion. The key aim of the study was to discover the research production and
its progress, research gaps, and future research directions in the domain of skills development in Construction 4.0 implementation. A total of 57 articles published since 2017 were selected as the literature sample. Annual scientific production validated the growing trend of Construction 4.0 studies on skills development. Keyword analysis identified 6 clusters such as emerging Construction 4.0 technologies, BIM as a Construction 4.0 technology, Construction 4.0 workforce, human factor in Construction 4.0, benefits of Construction 4.0, management roles in Construction 4.0. Co-authorship analysis revealed the productivity and influence of Feng Y. as the major contributor to collaborations with the expertise on BIM and robotics in construction. However, co-authorship analysis revealed limited collaborations, indicating that the domain is still in its early stages. Co-citation analysis showed significant connections between clusters, concentrating on Construction 4.0 implementation in various contexts, such as project management, skills management, and construction process management.

Document analysis of the most influential articles emphasized workforce and organizational structures as critical factors and a focus on the primary principles and behaviour of workers in a Construction 4.0 scenario. Research teams very active in the domain were from countries such as Malaysia, the UK, Spain, and China researching in the national context. Additionally, European countries showed considerable engagement in the domain, with a focus on professional skills development in respective national context.

Following the scientometric analysis, a qualitative discussion was performed utilizing the identified clusters to summarize the mainstream research topics in the domain and it was discovered that the majority of topics were concerned about Construction 4.0 whilst skills development aspect was lacking with regard to creation of policies, frameworks, strategies in different contexts. The study revealed research gaps such as presence of skills gaps in some countries and those countries that solved the skills gap have a skills shortage, the lack of frameworks and roadmaps for successful Construction 4.0 implementation, and the lack of readiness assessments from professional, company and industry viewpoints. Based on the above findings, future research directions were proposed in the study.

This review-based study in Construction 4.0 implementation focusing on skills development was limited to its literature sample filtered out through the bibliometric search only from 2017 to 2022. This study contributes to the knowledge in the domain of Construction 4.0 and the contribution of skills development for its implementation and a comprehensive overview with research gaps and future research directions in the domain. The importance of this study lies in the potential to inform policymakers, educators, and industry professionals on the necessary skills and strategies needed to address skill shortages and gaps in the construction industry. By providing socio-technical insights into the impact of Construction 4.0 on stakeholders and the necessary skills and strategies needed to address skill shortages and gaps, this research can inform decision-making and help to ensure successful implementation of Construction 4.0. The study’s findings can be used as a basis for further research on skills development in the context of Construction 4.0, providing a framework for stakeholders to align their efforts and minimize negative impacts.

References


Cerika, A. and Maksumic, S. (2017), *The Effects of New Emerging Technologies on Human Resources: Emergence of Industry 4.0, a Necessary Evil?*, University of Agder Faculty of Business and Law Department of Business Administration, available at: https://uia.brage.unit.no/uia-xmlui/handle/11250/2452946


**Corresponding author**
Robert Moehler can be contacted at: robert.moehler@unimelb.edu.au

For instructions on how to order reprints of this article, please visit our website: [www.emeraldgrouppublishing.com/licensing/reprints.htm](http://www.emeraldgrouppublishing.com/licensing/reprints.htm)
Or contact us for further details: permissions@emeraldinsight.com