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*Review*

# Governance, Standards and Regulation: What Construction and Mining Need to Commit to Industry 4.0

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**Abstract:** Digital transformation has become a pressing concern for the Australian government in the wake of COVID-19. While a thriving construction industry is key to Australia's economic recovery, the promised land of Industry 4.0 continues to elude the sector. Unlike the mining industry, which has obtained government funding to future-proof its workforce, the building industry remains at risk of being left behind because it has failed to prosecute the case for its own planned Fourth Industrial Revolution. A consistent approach to both sectors is needed to mitigate against asymmetries in the workforce and assist those transitioning from sectors devastated by COVID-19 by providing them with the high-tech skills which fortify the link between wages and employment. SMEs given their limited resources are also vulnerable, and the sector has been rocked by waves of insolvencies in recent times. Achieving Industry 4.0 success has long been a goal among industry academics yet hardly any attention is paid to the institution or its failures. This study subjected 59 authoritative articles to bibliometric analysis and systematic literature review and identified a dearth of research on how best to regulate Industry 4.0 and deliver the standards on which construction and mining businesses will depend when making the choice to commit to Industry 4.0. Nevertheless, there are valuable lessons to be learnt when it comes to supporting SMEs and workers embarking the risky business of Digital Transformation.

**Keywords:** Australia; construction; mining; digital transformation; standards; governance; regulation



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## 1. Introduction

Growing the digital economy and revitalizing high-tech manufacturing (Digital Transformation) have become top priorities for the Australian Government following the global outbreak of COVID-19 [1]. International border closures and public health orders which required office workers to stay home wherever possible forced businesses to rapidly adopt cloud and mobile computing to enable their personnel to continue working remotely. Such was the pace of change that within the first two months of the Pandemic, digitization is said to have surged by 5 years [2]. Overnight, the modern workplace became flat and fully digital.

Despite this the construction industry, which sought increased spending on public works gave little thought to securing its ticket to the digital Promised Land, and now faces the reality-check of unravelling global supply chains and a contagion of corporate collapses.

In contrast, the mining industry successfully lobbied for government funding to future-proof its workforce with upskilling and R&D, which will no-doubt serve it well in the long run as global demand for raw materials needed in electronics and renewable energy explodes [3].

Given their importance to national prosperity, a consistent approach to both sectors is needed to mitigate against asymmetries in the workforce and assist those transitioning from sectors devastated by COVID-19 by providing them with the high-tech skills which fortify the link between wages and employment [4].

Much has already been written in the academic literature about the construction industry's sluggishness when it comes to embracing change [5,6]. In addition, despite the widespread availability of cutting-edge technologies in Australia [2], the sector is plagued by engineering failures, litigation, lagging productivity and high rates of bankruptcy, on top of shocking levels of mental distress and suicide according to peak industry bodies [7].

Industry commentators worldwide have been calling for reforms for some time, and it is widely believed that Digital Transformation offers a pathway back to growth [8]. In particular, organizations like the World Economic Forum and the Big Four advisories have relentlessly preached a doctrine of digitization while proclaiming a Fourth Industrial Revolution [9]. In addition, countries like Germany [10], Japan [11], and China [12], have already launched platforms for transforming their economies.

In particular, Germany's Industry 4.0 has become highly influential among industry scholars concerned to progress Digital Transformation in Australian construction [13–16]. However, hardly any attention has been paid to its objectives, organization or failures [17,18], especially in relation to governance, regulation and standards [19]. With that in mind, the objective of this paper is to review the extant literature and give chase the following research questions:

I. Since the pandemic, to what extent does Industry 4.0 remain the benchmark for Digital Transformtion?
II. What are the strengths and weaknesses of Industry 4.0 as platform for Digital Tranformation?
III. How has Industry 4.0 research benefitted construction and mining?

## 2. Literature Review

### *2.1. Digital Transformation: Construction in Australia*

Leviäkangas et al. [5] recently investigated how the Australian construction industry compared with other sectors in terms of digitization. Using publicly available data, the authors observed that the construction industry invested approximately 1% of its share of GVA in ICT, placing it at the lower end of the spectrum compared to other industries (mining, it must be noted, returned similar results). However, as a proportion of its total investment (gross fixed capital formation), the construction sector invested around 15% elevating it to mid-range among its peers. The authors further noted that labour productivity in the sector was in fact the third highest despite the low level of investment in ICT contrary to the perception that the sector is lacking in this regard.

Whether productivity could be positively correlated with investment in digitization, remained unanswered by the authors, who suggest that a longer time frame, and investigation may produce more conclusive results. The authors further noted the difficulty in precisely establishing any industry's level of digital preparedness because of the diffuse nature of the private sector. They hint at, but fail to explore the role of the public sector in regulating Digital Transformation which, given the government's on-again-off-again commitment to transforming the sector, seems like fertile ground for further study [20]

Respectfully, there are other problems with Leviäkangas' research: its study of digitization is based on a narrow definition (i.e., capital investment in ICT, computers, software, peripheral devices and the like), which does not contemplate the myriad of cutting-edge technologies transforming the sector. Being *average* when the benchmark is set so low should be of little comfort to industry academics and practitioners.

Edirisinghe [21] extensively canvased the range of ground-breaking technologies set to revolutionize building sites. Particularly in relation to tracking worker's movements and execution of tasks on site. The construction site of the future, according to the author will involve increasingly intimate integration of human bodies and digital technology within a context-aware *digital skin*. Among the more intriguing innovations the author lists:

- *Wearables* with embedded sensors to monitor for hazardous conditions or exposure to noxious chemicals;

- *e-Textiles* which provide data on worker's physiological condition including pulse, respiration, and body temperature;
- *Exoskeletons* which limit muscular strain and enhance strength;
- *Smart PPE* which monitor eye movements for signs of fatigue (or drug abuse).
- *Biomedical Pads* capable of detecting brain activity to monitor cognitive engagement;
- *Embedded electronic devices* within the bodies of workers themselves linking them to sensors throughout the site.

The trend towards Biotech in construction cannot be easily dismissed as science fiction nowadays. As we have recently seen, modern industry has unwittingly stumbled over the biological frontier and must now contemplate increasing disruptions caused by microbiota [22]. If/when the sector commits fully to incorporating biotech in its processes stakeholders should anticipate an explosion in research on safety, civil rights and ethics to ensue.

### *2.2. Digital Transformation: Mining in Australia*

Holcombe and Kemp [23], considered the impact of Digital Transformation on Indigenous and First Nations communities located near mining operations in Australia and Canada. The authors noted that industry participation rates among these communities had increased to unprecedented levels over the last two decades under novel land usage agreements, company policies and regulations.

The authors discuss the risks posed by automation and mechanization of low-skilled work on which remote Indigenous and First Nations communities located near mining operations are often heavily reliant. They warn against the uncritically positive assumptions underscoring technological innovations by calling attention to adverse impacts which are chronically underrepresented in both the extant literature and corporate discourse. The authors call on government to urgently engage with the problems of automation and digitization in remote Indigenous and First Nations communities and highlight five pressing areas for future research:

- Risk and social impact
- Work and welfare
- Work and education
- Land and the indigenous estate
- Human rights and development

### *2.3. Digital Transformation: Industry 4.0 in Australia*

Claire in a recent study [16] conducted by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia's peak scientific body, interviewed 20 domestic manufacturers actively pursuing Industry 4.0 adoption. The participants included manufacturers of metal, wood, and polymer products, as well as transport equipment of which the construction industry is a major consumer. The study identified the key steps necessary to achieve success in implementing Industry 4.0 which include:

- *Strategy and leadership*: adoption must be driven by a commitment to achieving clear aims and objectives by company executive.
- *Organisational culture*: the company structure must be horizontal and oriented towards continuous innovation.
- *Governance, safety and security*: a rules-based environment which promotes safety and data security is essential.
- *Workforce:* roles must be redefined to eliminate repetitive tasks, promote autonomy and continuous learning.
- *Smart products and services:* value-adding technology must be embedded in the products and services of the company.

The study found that most participants focused on digital integration, that is, incorporating connective technologies which enable the acquisition of data in real time, with little thought to the above-mentioned steps. Despite the inherent risks of widespread data exchange, governance safety and security (Governance) were the factors least discussed by the study participants. Accordingly, the authors recommended that Government should mainstream Industry 4.0 adoption across key value chains in this country by creating appropriate regulations and standards.

With the above in mind this author looks to the international literature for further guidance on the trajectory of Industry 4.0 as it pertains to construction and mining. In addition, the remainder of this paper is structured as follows. Section 3 presents the methodologies selected to address the questions proposed by this research which include bibliometric analysis and systematic literature review (SLR). Section 4 reports the findings of each approach. Section 5 includes a discussion synthesizing the findings, an acknowledgement of the limitations of this research and a statement as to its implications. While Section 6 presents a brief conclusion summarizing the major contribution of this work.

## 3. Methodology

To begin addressing the questions proposed by this research, a representative sample of authoritative international papers is required. Several systematic searches were conducted using two widely used online databases, namely SCOPUS and the Web of Science (WoS) [24]. Two databases were searched to minimize the chance of missing articles which merit inclusion. Both were selected for their coverage of technological research, with Scopus chosen for its breadth and WoS for its depth. This approach enabled identifying articles related to construction and mining as specific disciplines on Web of Science, and then cross-checking the results on Scopus for additional records, bearing in mind that almost all journals listed on WoS are also on SCOPUS [24].

To answer questions I and II, bibliometric analysis of the metadata was used to provide an objective appraisal of the literature. Bibilimetrix [25,26], an open-source *R*-tool for statistical mapping, was selected to carry out this analysis. Bibliometrix is a user-friendly program for processing large volumes of literary material expeditiously and requires no expertise in coding. Bibliometric tools provided by SCOPUS were also used to examine results obtained from that database.

Systematic literature review (SLR) was selected as the method most appropriate for answering question II and III. SLRs are an important component of all academic studies, since it prevents missing a relevant publication using the same keyword in its title or abstract [26] SLR serves as a starting point by establishing what research has already been done, a means of identifying gaps in what is known, and a guide as to possible directions for future research [26,27]. SLR also serves as a record of how research has been carried out by being transparent and reproducible because details of the review are clearly presented.

### *Systematic Searches*

An exploratory search of the literature using Google Scholar was first conducted to obtain examples of keywords which were suitable for inclusion in the search parameters. These were organized thematically to facilitate drafting search queries for WoS and SCOPUS. See: Tables 1 and 2.

Using PRISMA, results were then iteratively screened based on criteria predetermined to facilitate answering the research questions. These include limiting the relevant period to between 2011 and the present (given Industry 4.0 was launched at the 2011 Hannover Fair [10], screening for relevant subject areas such as engineering, construction management and so forth, language of publication, and sources. To ensure the results were of a high quality the author also limited selection based on number of citations. See Figure 1.

**Table 1.** Parameters used to query SCOPUS and Web of Science.

| Industry 4.0 | Digital | Transformation | Construction | Mining |
|---|---|---|---|---|
| Industrie 4.0 | Technology | Readiness | Building | Primary |
| Fourth Industrial Revolution | Innovation | Maturity | Industry | Resources |
| 4th Industrial Revolution | | Implementation | Industry | Extraction |
| Industrial Internet of Things | | Diffusion | Sector | Energy |
| IIOT | | Adoption | | Industry |
| | | | | Sector |

**Table 2.** Search parameters used to query SCOPUS and Web of Science.

| Action | Query |
|---|---|
| Search 1 | (Industry 4.0) OR (Industrie 4.0) OR (Fourth Industrial Revolution) OR (4th Industrial Revolution) OR (Industrial Internet of Things) OR (IIOT)<br>AND<br>Digital OR Technology OR Innovation<br>AND<br>Transformation OR Readiness OR Maturity OR Implementation OR Diffusion OR Adoption OR Acceptance |
| Search 2 | (Industry 4.0) OR (Industrie 4.0) OR (Fourth Industrial Revolution) OR (4th Industrial Revolution) OR (Industrial Internet of Things) OR (IIOT)<br>AND<br>Digital OR Technology OR Innovation<br>AND<br>Transformation OR Readiness OR Maturity OR Implementation OR Diffusion OR Adoption OR Acceptance<br>AND<br>(Construction Industry) OR (Construction Sector) (Building Industry) OR (Building Sector) |
| Search 3 | (Industry 4.0) OR (Industrie 4.0) OR (Fourth Industrial Revolution) OR (4th Industrial Revolution) OR (Industrial Internet of Things) OR (IIOT)<br>AND<br>Digital OR Technology OR Innovation<br>AND<br>Transformation OR Readiness OR Maturity OR Implementation OR Diffusion OR Adoption OR Acceptance<br>AND<br>(Mining Industry) OR (Mining Sector) OR (Extraction Industry) OR (Extraction Sector) OR (Primary Industr*) OR (Primary Sector) OR (Resource* Industry) OR (Resource* Sector) OR (Energy Industry) OR (Energy Sector) |

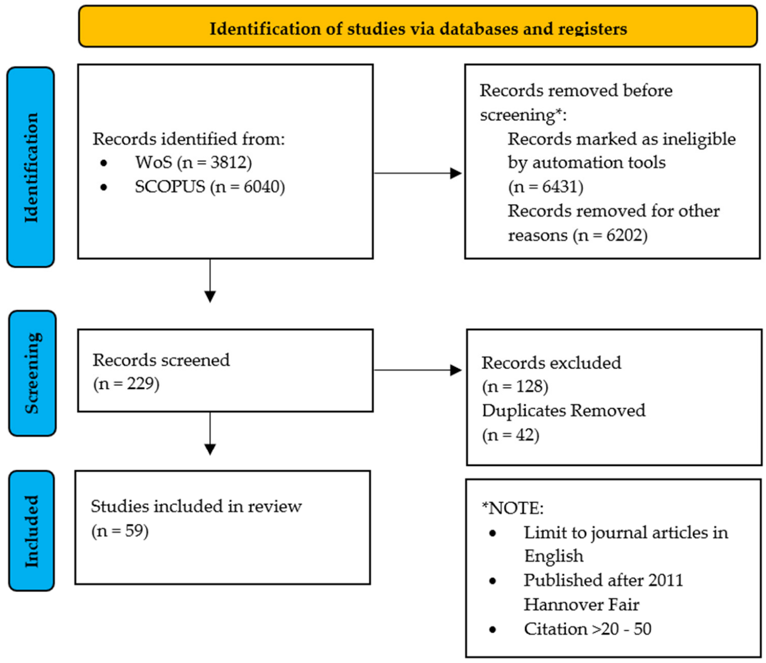


**Figure 1.** Systematic search results (Source: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* **2021**, *372*, n71. http://doi.org/10.1136/bmj.n71).

## 4. Findings

### 4.1. Bibliometric Analysis: Leading Industry 4.0 Scholars

The top ten authors were ranked by relevance, that is, in terms of the number of articles included in this review (see: Figure 2), which was disaggregated to show their relative contribution to the body of work (See also: Figure 2). According to the data, Müller has been the most productive scholar within the period and can claim authorship of just over 50% of the total number articles to which authorship has been attributed. Which is unsurprising given the obvious strategic advantage German scholars have in setting the pace of research on Industry 4.0.

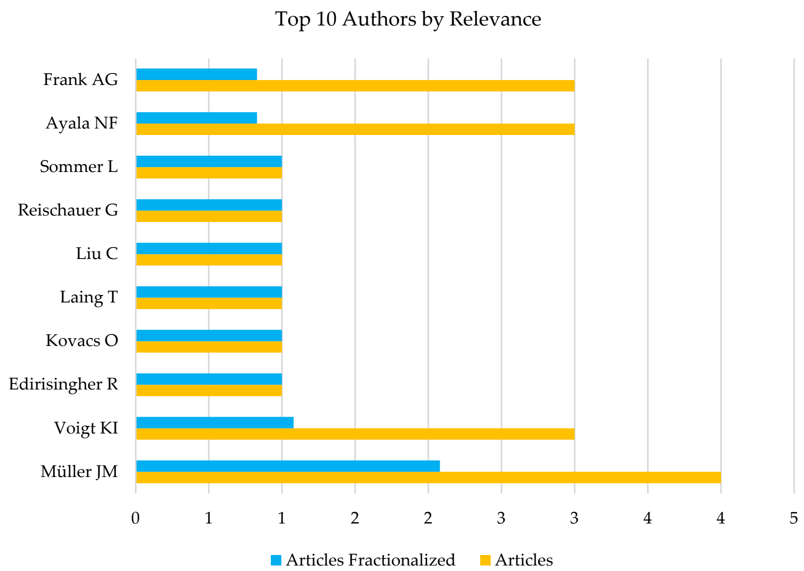


**Figure 2.** Top ten most relevant authors as calculated by Bibliometrix.

The top ten articles were then ranked in terms of global citations, meaning the total number of citations by scholars worldwide; and local citations or the total number of citations by scholars included in this review (See Figures 3 and 4). In both instances, Lasi's brief 2014 [10] article is the most cited work, nearly doubling the next in rank. Which speaks to this author's particular influence on the direction of research. Interestingly, Oesterreich and Teuteberg's 2016 article [19] on construction and Industry 4.0 is among the most cited papers locally and globally, well above Müller's.

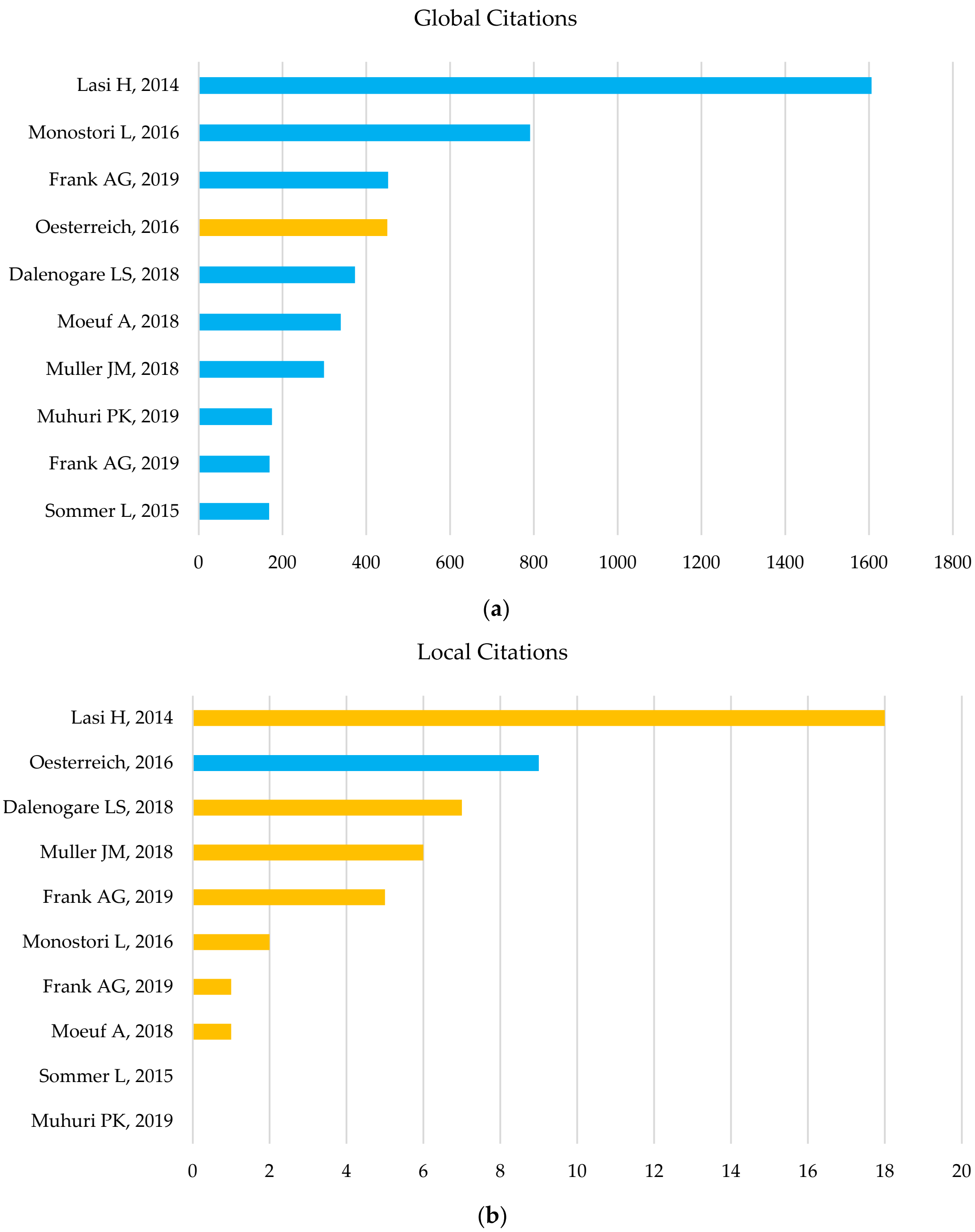


**Figure 3.** (**a**) Top ten most cited articles (globally) as calculated by Bibliometrix. (**b**) Top ten most cited articles (Locally) as calculated by Bibliometrix.

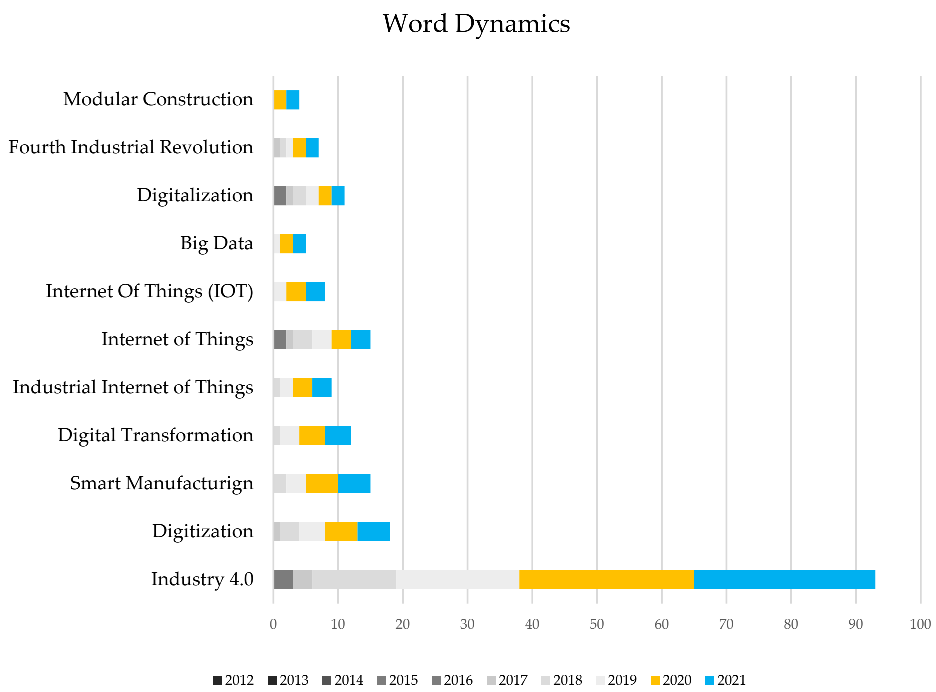


**Figure 4.** The most dramatic increases in the use of "Industry 4.0" coincide with the global outbreak of COVID-19.

### *4.2. Bibliometric Analysis: Word Dynamics and Topic Clusters*

Cumulative changes in keyword used by authors included in this study were also ranked, and the data reveals that Industry 4.0 has surged since the outbreak of the Pandemic (See: Figure 4). While Figure 5 sets out the top five topic clusters by scholarly output, field-weighted citation index, and worldwide prominence percentile. As can be seen, construction site monitoring and facilities management are the trending industry-specific topics among scholars captured by this study.

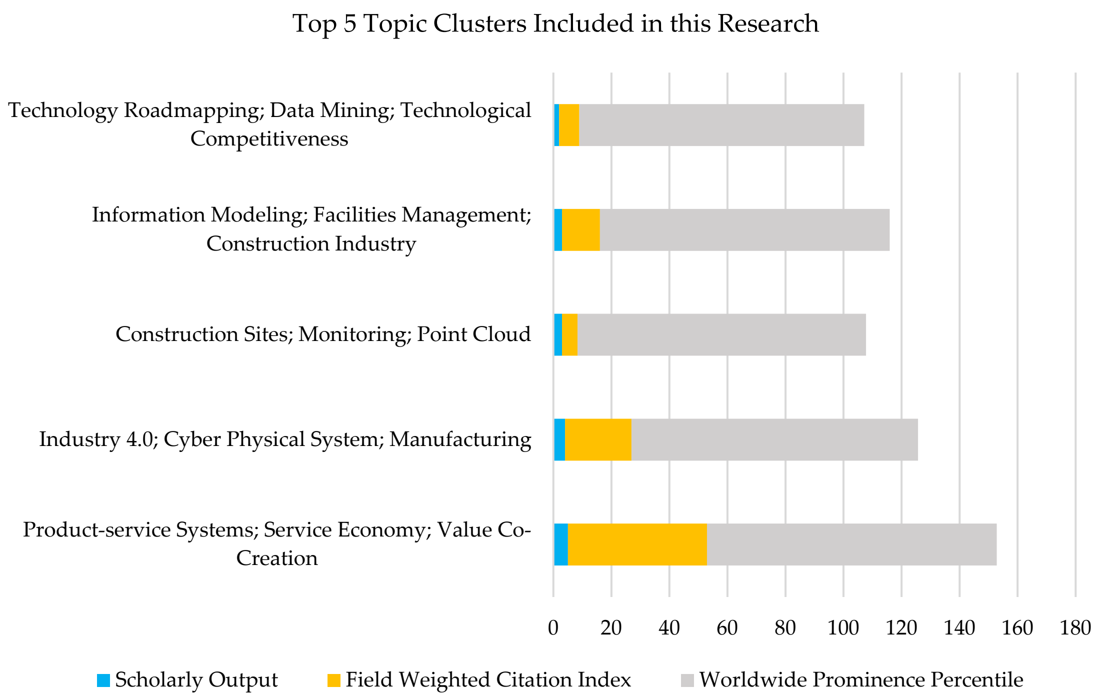


**Figure 5.** Top five topic clusters identified among the papers chosen for inclusion in this research.

Ironically, it appears that construction industry academics have been leading the charge when compared to their peers in mining. Of the articles determined to be eligible for this study, only a handful directly relate to mining operations ($n = 4$). While the number of construction industry articles was quadruple that amount. The remainder ($n = 39$) related to Digital Transformation and Industry 4.0 as general subjects of inquiry.

### 4.3. Critical Content Reiview: Digital Transformation in Construction and Mining

Woodhead [6] undertook a longitudinal survey of the literature on disruptive technologies reshaping the construction industry in the UK and called for an evolutionary rather than revolutionary understanding of Digital Transformation. Using a historicized socio-technical approach, the author cites a range of broader socio-political and demographic factors which influence the pace of change in that country including BREXIT, economic austerity and an aging workforce. In addition, they make the case for industry reform in response to several worrying socio-economic symptoms.

In particular, the author calls out a culture of resistance to change as demonstrated by low uptake of certain research and development tax incentives set up by the UK government to stimulate innovation in the industry. Without delving further into the reasons why, the authors instead focus on the promise of digitizing the sector as big data becomes increasingly abundant across the construction project lifecycle. It naturally follows, however, that these hypothetical benefits will be of no avail if, by the authors' own admission, the industry simply does not see itself as a leader of innovation. What this research lacks is a cogent explanation of why that remains so, and where then should leadership come from? The authors observe that "*the ingredients for an IoT ecosystem are known in the construction industry. What is often missing is a bold vision* . . . " [6].

Xu, Zayed [28] considered the role of government as both a regulator, consumer and advocate for modular construction. Their research comparatively analyzed the regulatory environment in Southeast Asia and concluded that strong government support was the key to mainstreaming novel procurement methods. Of the countries examined Singapore was found to be the most advanced, despite significant economic challenges, labour and supply chain issues. They helpfully outlined the Singaporean Government's framework of policies, regulations, investment vehicles, technology and supporting activities used to incentivize adoption and innovation in the sector. Notwithstanding the regional specificity of the authors' research, their work opens to door for further investigation of, and comparison with the Australian context. Indeed, it is telling that Singapore, with its limited workforce, landmass and natural resources has adopted this method for delivering housing and infrastructure earlier than Australia which is far better placed to overcome the challenges involved.

Young and Rogers [29] addressed Digital Transformation of the American mining by outlining the key technological drivers of change for that sector, suggesting three high-level "*components*":

- Connectivity
- Data
- Decision making

The authors further set out the attributes of each component by discussing how data is generated on mining sites, the infrastructure required for connectivity, and how analytics enhances decision making at the business level. Curiously the study does not cover the role of technologies like robotics and autonomous vehicles in driving the pace of Digital Transformation, and it is unclear whether this is influenced by market maturity, resistance to change or other factors. The authors further discuss the evolving role of education in shaping the skillset of the workforce noting the proliferation of courses of study which relate to analytics and artificial intelligence, a trend the construction sector should embrace with gusto.

### *4.4. Critical Content Review: Industry 4.0—Organizational Structure and Strategic Objectives*

Industry 4.0 (*Industrie 4.0* in German) is a German government initiative to modernize that country's manufacturing sector, which was launched in 2013 by the Federal Ministry for Economic Affairs and Energy (*Bundesministerium für Wirtschaft und Energie*) [30]. It is the outcome of the federal government's "*Action Plan High-Tech Strategy 2020*" and is tasked with facilitating "*cooperation between all actors of innovation in Germany*" under a holistic vision of Digital Transformation. This is accomplished by coordinating dialogue, research, funding, standardization, international cooperation, and implementation. Industry 4.0 is comprised of six working groups:

- Reference architectures, standards and norms
- Technology and application scenarios
- Security of networked systems
- Legal frameworks
- Work, education
- Digital business models in Industry 4.0

It oversees a network of innovation hubs, institutions and pilot projects providing support services to SMEs across Germany [30]. Over 150 companies are involved in the Platform, which claims to be, "*the world's largest network for Digital Transformation in the industry*" [30]. Industry 4.0 is further supported by the Research Council Industry 4.0, an independent research organization at the National Academy of Science and Engineering (ACATECH: *Deutsche Akademie der Technikwissenschaften*), [31] which monitors and advises on Digital Transformation. The council's key research themes include:

- Value creation scenarios
- Technological trends
- New methods and tools
- Work and society

Conceptually, the vision for Industry 4.0 links three core principles which reflect Germany's strategic objectives [32]:

- *Autonomy*, which requires universal access to digital infrastructure, where users can safely and securely conduct business, research, and development;
- *Interoperability*, which concerns creating a standardized, rules-based environment to ensure the beneficial use of artificial intelligence and big data; and
- *Sustainability*, which means fostering ongoing employment in high-quality jobs, high levels of participation by German workers and embracing the technological challenges presented by climate change.

Reischauer [17] recognizing the proactive character of Industry 4.0, advances the innovation discursive view as *the* fundamental attribute of Industry 4.0. The author helpfully outlines the formalization of the German government's initiative, including the establishment of a dense network of research institutions in Westphalia which comprise a triple helix model of innovation (i.e., industry, academia and government collaboration).

Reischauer's work makes a significant contribution by calling attention to the political complexity behind the Industry 4.0 concept: simultaneously an institutionalized innovation complex developed and deployed by a national government with concrete goals and stakeholders; and a multichannel communication platform for producing, disseminating, and reinforcing an agenda for Digital Transformation. Noting that Germany is a coordinated market economy, Reischauer, on future research directions, calls for comparative analyses of other innovation discourses in liberal market economies such as Australia.

### *4.5. Critical Content Review: Industry 4.0—Scholarly Output*

Despite its institutional robustness, an examination of the scholarly output paints a less balanced picture. In Figure 6, the top 100 most cited articles on Industry 4.0 (across all disciplines) have been ranked using SciVal. As can be seen, Engineering, Computer Science and Business are disproportionately represented in the scholarly output in comparison to Environmental Science, Medicine, and the Humanities.

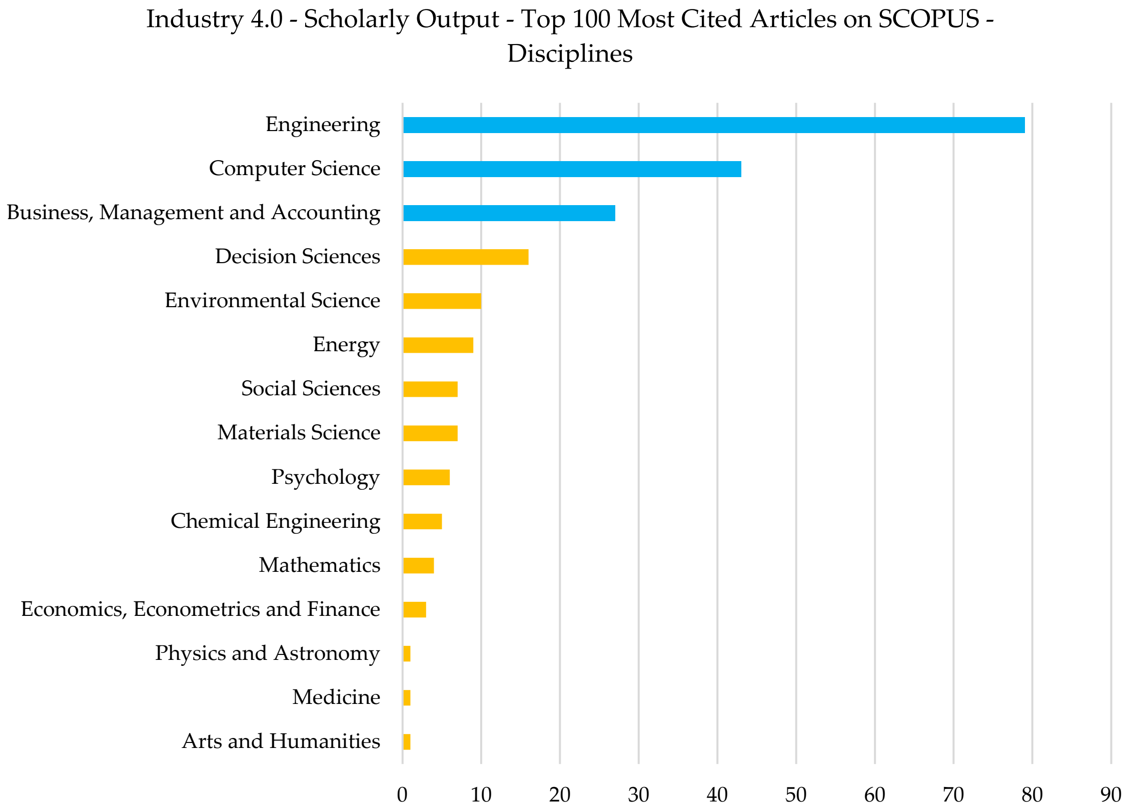


**Figure 6.** Top 100 Industry 4.0 articles grouped by discipline.

A closer inspection of the key topics reveals the Platform's chronic inability to even-handedly coordinate the academic discourse (See: Figure 7). At issue is the institution's express commitment to "*decent work and education*" and "*social inclusion*", while no meaningful engagement with the human aspects of Industry 4.0 is evident in the data.

Change is risky business for workers. It involves a commitment to continuous learning while just trying to make ends meet. Inevitably some will fail to make the transition due to lack of access to resources [33], worse others will be exploited under systemic inequities hardwired into the modern workplace [34]. Comorbidities which academia must bring to the attention of policymakers. Stringent regulation of the labour market to see of the risk of precarious employment must be priority number one for Industry 4.0 proponents [18].

Consider, for example, e-commerce, the posterchild of Digital Transformation, and the appalling union-busting practices of certain online retailers [35]. Or the way in which racism and sexism have been codified in the algorithms of online job-seeking platforms [36]. Not to mention the criminogenic effects of working conditions in mining operations [37] and the horrific working conditions faced by countless women and children working on mines across the global south to supply the very raw materials that make Digital Transformation possible [38].

Another red flag is the concerning silence in the literature on "*autonomy*" and "*interoperability*" [39]. A probative search of Scopus using the following query returned just 5 results among over 88,000 Industry 4.0 articles available online:

> TITLE((Industry 4.0) and Standard* or Regulation*) AND (LIMIT-TO (EXACTKEYWORD,"Interoperability") OR LIMIT-TO (EXACTKEYWORD,"Standardization") OR LIMIT-TO (EXACTKEYWORD,"Standards")) AND (LIMIT-TO (LANGUAGE,"English")) AND (LIMIT-TO (SRCTYPE,"j"))

Yet the research suggests that standardization may well be the Rosetta Stone of industry 4.0 adoption [40]. Standards make interoperability among participants in a Smart Factory environment possible and late adopters like construction businesses will depend on certainty regarding standards and regulations when transition to Smart Factories and Smart Construction Sites become key to their survival.

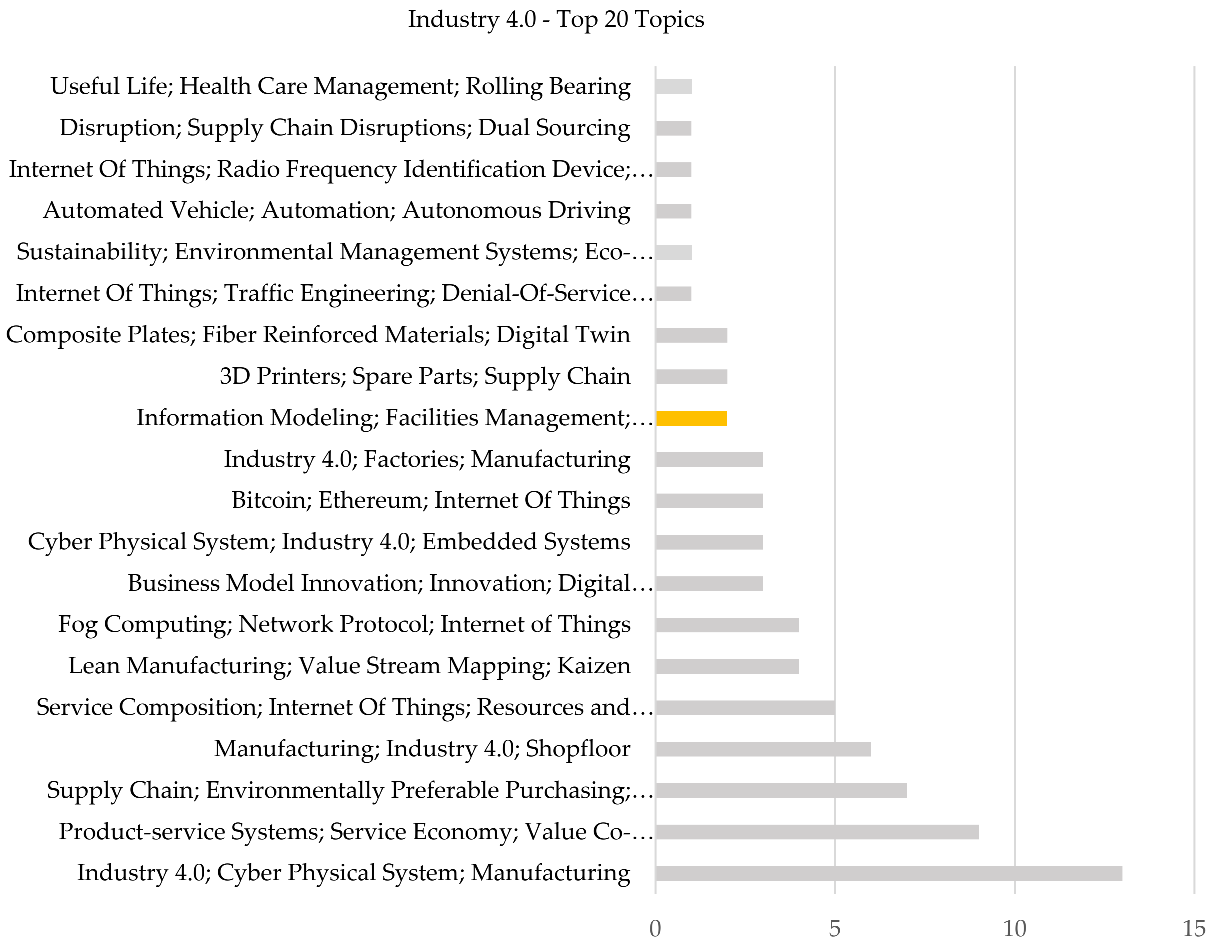


**Figure 7.** Top 20 Industry 4.0 topics by scholarly output.

### *4.6. Critical Content Review: Industry 4.0—Implimentation and Lessons Learned*

As reported in the bibliometric findings of this study Industry 4.0 has outpaced other keywords preferred by academics since the outbreak of COVID-19 (See: Figure 4). The phrase Industry 4.0 came into international use after the 2011 Hannover Fair, following a presentation by the steering committee for *Platform Industrie 4.0* [10] While the Platform's website defines Industry 4.0 simply as, "*the intelligent networking of machines and processes for industry with the help of information and communication technology*" [30], much effort has since gone into consensus among non-German academics and practitioners as to what it means. However, the range of definitions in the academic and grey literature is unhelpfully wide and tends to be comprised by prescriptive lists of advanced technology must-haves

In some instances, Industry 4.0 has become synonymous with the "*Smart Factory*" [41], a fully digitized, robotic manufacturing environment controlled by cyber-physical systems ("CPS") that blur the boundaries between man and machine [42]. Which is unhelpful because:

i. It sidelines the complex formal relationships, policies, networks, public funding, and support structures which have been built over time around the German vision;
ii. It says nothing of the difficulty of transitioning existing workforces and small to medium enterprises ("SMEs") without considerable government support; and
iii. It says even less about adapting heavy industries like construction and mining.

Lasi, Fettke [10] et al. wrote an especially influential (though brief) article on Industry 4.0, positing it as a "*planned Fourth Industrial Revolution*" instigated by the Federal Ministry of Education and Research (*Bundesministerium für Bildung und Forschung*). In addition, proposed several fundamental attributes of Industry 4.0:

- The smart factory;
- Cyber-physical systems; and
- Self-organizing, decentralized manufacturing systems.

which may have unintentionally misdirected the course of research on Industry 4.0 by focusing attention on implementation over Governance.

Naturally, investigating the extent to which Industry 4.0 has been implemented is an important topic among German academics, and various studies have been conducted in pursuit of this objective. Sommer [43] conducted a systematic review of nine studies on German manufacturing. The review considered the technical/economic and psychological impacts of Industry 4.0 and concluded that SMEs were at higher risk of becoming victims of digitalization under the scheme and need special government support to survive Digital Transformation.

Müller [44] qualitatively investigated how 68 German SMEs from three industries approached business model innovation under Industry 4.0, and showed that success hinges on three dimensions:

- High-grade digitization of processes;
- Smart manufacturing;
- Inter-company connectivity.

Müller [45] further investigated implementation from the perspectives of 41 workers at a German manufacturing plant in 2019, and found that workers mostly feared their substitution, lack of support, and having to re-skill mid-career.

Veile, [46] carried out a '*lessons learned*' study on Industry 4.0 implementation, considering the experiences of 13 German industry experts, which revealed insights across a range of domains: skills, training, safety, integration, funding, organizational structures and interconnectivity.

Internationally, academics have also taken a keen interest in Industry 4.0. Among these Liu's 2017 article is particularly useful [47]. The author sets the scene for a broad discussion by locating Industry 4.0 within the evolution of theories on international competition. Noting the macro- and micro-economic factors that drive innovation and technological development, the author explains the way in which the socio-political climate (for example, the rule of law, monetary, innovation and environmental policy, workforce skills and capabilities) and strategic factors (such as geography, location and natural resources) influence innovation at the industry level. Liu emphasized the importance of taking advantage of existing strengths, proximity to other innovators and consumer expectations in a thriving high-tech ecosystem. Accordingly, a coordinated and consistent response with advanced technology as simply the means of achieving a competitive advantage is advocated by the author. However, international efforts to adopt Industry 4.0 have been sporadic exploratory at best.

For example, Frank and Dalenogare [48] analyzed implementation of Industry 4.0 technologies among 92 manufacturers in Brazil and proposed a three-staged conceptual framework for Industry 4.0 adoption based on their findings. Meanwhile, Tortorella, Cawley Vergara [49] looked at the mediating effect of organizational learning on the impact of Industry 4.0 adoption by 135 Brazilian firms. Raj, Dwivedi [50] compared the differing barriers to implementing Industry 4.0 technologies in India and France. In addition, Horvath and Szabo [51] considered the barriers to Industry 4.0 in Hungary. However, what is unclear in these works is whether, and to what extent, the governments of Brazil, India or Hungary have seriously committed to Industry 4.0.

Similarly, Santos [52] discussed the impact of Industry 4.0 on European Union strategic policy in their 2017 article. The authors mapped the convergence of certain technological drivers and Industry 4.0 design principles within a range of EU strategic roadmaps prior to and after Hannover 2011. Unhelpfully, however, the author fails to provide reasons behind the trends or any predictions as to future directions in EU innovation policy.

Kovacs [18] in contrast urges caution and calls for a more "*complexity-aware*" approach to Industry 4.0 by pointing out the downsides of Digital Transformation. He warns against neglecting context and balance between innovation policy the short-lived risk appetite of the financial sector. Scholars, Kovacs argues, must be wary of the false promise that labour market flexibility brought about by deregulation and automation will lead to gains in productivity. As demonstrated by income stagnation and labour precarity in the United States when compared to the European Union. Kovacs calls for a Governance framework to manage this transition with due regard to the common good. The salient features of which include, incremental change, and compensation for those made worse-off.

### *4.7. Critical Content Review: Industry 4.0, Construction and Mining*

A systematic search of the extant literature yielded only a handful of articles on how industry 4.0 as a platform was transforming construction or mining. Given the centrality of consumer goods manufacturing to the German economy, this is hardly surprising [53]. In Germany, four industries dominate—automotive, mechanical engineering, chemical and electrical industries—and contribute around 18% of GDP [54]. Which is reflected in the key objective of Platform Industrie 4.0: "*The overarching goal of the Platform Industrie 4.0 is to secure and expand Germany's leading international position in the manufacturing industry*" [30], and its strong emphasis on consumer-oriented solutions [30].

Oesterreich and Teuteberg [19], noting the lack of awareness of Industry 4.0 in the construction sector, conducted a comprehensive literature review and observed that while the sector was lagging behind others in terms of digitization, several key technologies which underpin the Industry 4.0 concept had nevertheless reached market maturity in that industry, and were widely available. Chiefly:

- Building Information Modelling
- Internet of Things (IoT)/Internet of Service (IoS)
- Product Lifecycle Management (PLM)
- Cloud Computing
- Mobile Computing

Oesterreich and Teuteberg's study also included case studies of several construction companies of varying sizes, predominantly located in the US and UK. In addition, a comprehensive summary challenges and benefits to adopting Industry 4.0 technologies were tabled by based on the extant literature; however as to the order of priority or value added by each item within the author's framework, more research is called for. Crucially, the authors criticized the tendency among researchers and industry commentators to focus on the technological applications while neglecting research on Governance.

Lööw [55] envisaged the impact of Industry 4.0 from the perspective of workers in the mining sector. They explored possible scenarios of industry transformation, including the impact on the nature of work, the workplace of the future, employee satisfaction and identity, and the urban rural divide. Interestingly, the authors describe their conception of a typical worker and how they might feel about the changes to their workplace and community brought about by digitization and automation. The authors contrast two visions of the impact of industry 4.0 (dystopic and utopic) to illustrate the potential risks and opportunities from a worker's perspective. They explore often overlooked themes such as job satisfaction, boredom, personal development, migration, alienation, team building, mental health, identity, creativity, privacy, conformism, surveillance, and intimidation. In addition, it is not hard to imagine the corrosive potential of a half-baked Industry 4.0 strategy on individual workers. The authors conclude with six high-level recommendations for beginning a roadmap for implementing industry 4.0 in the mining sector. These include:

- Striking a balance between the profit motive and social equity;
- Re-skilling existing workforces to mitigate digital joblessness;

- Empowering workers by incorporating their aspirations;
- Creating flat organizations which extend to surrounding communities;
- Commitment to cooperating with trade unions;
- Implementing change responsibility.

Dallasega et al. [56] in their study considered the impact of Industry 4.0 technologies on construction supply chain management. A systematic review of the literature revealed the range of Industry 4.0 applications which enhanced technological, organizational, geographical and cognitive proximity. The authors further observed that Industry 4.0 had no discernible impact on social, cultural, or institutional proximity in that sector. Which is remarkable given the scourge of modern slavery, sweatshops and human trafficking entrenched in the global supply chain for smart technologies [57].

Mudan et al., in their 2020 article [13], considered Industry 4.0 in the context of off-site construction ("**OSC**"). Noting the rising popularity of OSC in certain industrialized countries including Australia, the authors provide a scientometric and systematic review of current articles identifying key technologies associated with Industry 4.0 and adopted the sector, including:

- Building Information Modelling (BIM)
- Radio Frequency Identification Devices (RFID)
- Global Positioning Systems (GPS)
- The Internet of Things (IoT)
- Geographic Information Systems
- Sensors
- Augmented Reality (AR)
- Virtual Reality (VR)
- Photogrammetry
- Laser scanning
- Artificial Intelligence (AI)
- 3D printing
- Robotics
- Bigdata
- Blockchain.

Mudan et al. provide a useful summary of each technology's application (and issues) in their appraisal of the state of the art in OSC. However, while the authors do not go as far as to discuss the social merits of OSC, they nevertheless set the stage for mainstreaming OSC in countries like Australia.

## 5. Discussion

### *5.1. Synthesis*

This research is born of the vexed issue of Digital Transformation in the Australian construction sector, which has earned a reputation as a late adopter of advanced technology. This was recently demonstrated in the political arena by its failure to follow the mining sector's lead and advocate for funding to future-proof its workforce in the wake of the pandemic. Academics concerned to usher in change have enthusiastically embraced Industry 4.0 as the gold standard for Digital Transformation. However, little attention has been paid to the Industry 4.0 platform itself, or its structural failures. With that in mind, this research aimed to review the literature and pursue the following research questions:

I. Since the pandemic, to what extent does Industry 4.0 remain the benchmark for Digital Transformation?
II. What are the institutional strengths and weaknesses of Industry 4.0 as a platform for Digital Transformation?
III. How has Industry 4.0 research benefitted construction and mining?

To answer these questions 59 authoritative articles were identified from the literature and subject to bibliometric analysis using open-source R-tools in addition to systematic literature review. The top authors were ranked based on scholarly output. Their articles Were also ranked based on local and global citations, areas of study and topic clusters.

According to the data, Oesterriech's [19] 2016 article remains among the most relied upon by scholars, even more so than the most statistically relevant author on Industry 4.0 (see Figures 2 and 3). However, industry academics have failed to answer Oesterriech's calls for more research on Governance since its publication. Instead, the data reveal that the research on Industry 4.0 remains stubbornly skewed towards high-tech applications and their implementation on an ad hoc basis.

The lack of attention to Governance is not unique to construction or mining industry scholars. In general, the humanities are strikingly under-represented in the research. Which does not reflect well on Platform Industry 4.0′s ability to evenhandedly coordinate the discourse in accordance with its stated objectives, especially its abiding commitment to the dignity of work. Another concern is the dearth of research regarding standards and regulation on which late adopters like construction businesses will depend when transitioning to Smart Construction and Smart Manufacturing become key to their survival.

The main focus of research by industry academics has been on construction site monitoring and facilities management, which is, in fact, among the most popular Industry 4.0 topics irrespective of discipline (see Figure 7). Industry 4.0 for Off-Site Construction is curiously underrepresented in the literature, given that it presents as the most obvious fit for Industry 4.0's Smart Factory concept. In that regard, Singapore's mandate for delivering housing and public infrastructure may be a useful model for mainstreaming OSC. Australia with its vast natural resources, landmass skilled workforce and peak industry bodies is far better placed to adopt this method of procurement for public assets. The critical factor will be raising awareness of the standards required by mature Industry 4.0 cyber-physical systems within a Smart Factory setting.

Transforming the sector will also hinge on a conscious commitment by government to usher in beneficial change. The research clearly shows that without government support, SMEs with their limited resources and income struggle to reach Industry 4.0 maturity [43,44]. Given the building industry is overwhelmingly comprised by SMEs, the lessons learned from Germany's manufacturing sector must be incorporated by Industry 4.0 proponents. Bluntly put, the sporadic project-based nature of construction does not lend itself to a culture of ongoing innovation and continuous learning. In addition, decades of tax incentives and half-hearted government initiatives have failed to inspire voluntary change despite widespread availability of Industry 4.0 technologies [6].

With that in mind, another valuable lesson is a sober awareness of the threat Industry 4.0 poses to workers' sense of identity and agency. The fear of digital joblessness must not be underestimated as the sector transforms [45,55]. We are already seeing the real-world effects of chronic mental distress in construction and mining [58] and it is well established that these workplaces are among the most likely to affect health and involve deaths onsite [59]. Arguably the most confronting trajectory of Digital Transformation will be the biotech frontier. With the Fourth Industrial Revolution [9] set to challenge the very nature of humanity the sector must ready itself for engaging with profound questions as to the boundaries between biology and technology. As we have recently seen, the pandemic has forced industry to grapple with life and death issues in ways hitherto unimaginable.

Indigenous communities in Australia are at particular risk of losing out to automation and mechanization without adequate support in transitioning their fragile economies to Industry 4.0 [23]. Yet only a handful of researchers have urged due consideration of the downsides of Industry 4.0 and what it takes to protect those most likely to be made worse off [18,45,55].

The mining sector is far better placed to reap the benefits of Industry 4.0 owing to the small number of large global enterprises which command the majority of the market. Moreover, the timeline of mining operations is considerably longer than even very large construction projects. Which means committing to Industry 4.0 is more likely to stack up financially. However implementing Industry 4.0 must engender a sense of personal agency and solidarity among members of remote communities which service and supply mining operations [55].

Recent signals from industry have made the nexus between the humanities and industry crystal clear in practical terms. For example, the World Economic Forum, the original proponent of the Fourth Industrial Revolution concept, has flagged eroding social cohesion as being fourth among the top five global risks likely to be faced by humanity over the next decade after climate change and catastrophic natural disasters [60]. While peak industry bodies in this country have raised concerns about the malicious use of social media spread mis/disinformation [61] which has facilitated the infiltration of far-right extremists in the sector under the pretext of defending *Bodily Integrity* [61–63].

Nevertheless, the Industry 4.0 model has seen tremendous growth since the pandemic, far outpacing keywords used by academics in the last two years alone. The principal advantage of Industry 4.0 is its dense network of R&D institutions built over time with the backing of the German government and major commercial stakeholders. Despite its esteem, Industry 4.0 suffers several shortcomings of which policymakers and academics in countries like Australia need to be aware.

Firstly, it has achieved limited success in transforming German manufacturing, only four percent of businesses in that country have achieved Industry 4.0 success so far according to ACATECH [16]. Secondly, it has made very few inroads in heavy industries like construction and mining [19]. Thirdly, academics have tended to peg Industry 4.0 “success” to implementation and commercialization rather than social transformation [19]. In addition, fourthly, it has delivered limited new knowledge of its governance, standardisation and regulation.

Finally, academia must do more to anticipate the challenges of Digital Transformation [29]. Industry 4.0 is as much a discursive space as it is a platform for Digital Transformation [17], and built environment faculties would do well to follow the lead of their colleagues in engineering by providing courses which equip students with skills in analytics, artificial intelligence, mechatronics and the like. However, this must not be at the expense of the Arts and Humanities. In fact, these disciplines are vital to ensuring Industry 4.0 stays on mission.

### 5.2. Recommendations

With the above in mind, it is recommended that industry scholars realign their priorities by engaging with the urgent need for research on governance, regulation and standards. As Digital Transformation intensifies, building companies will depend on certainty regarding these matters when deciding to commit to Industry 4.0. Digital Transformation is especially risky to workers and SMEs and their legitimate fears must be met by compelling research as to the way forward.

### 5.3. Limitations of This Research

The ambit of Digital Transformation is wide, and this review has not considered important topics such as the circular economy and climate change. It also does not consider particular technologies and the relative benefits of their adoption.

### 5.4. Implications

This research is aimed at academics advising policymakers, industry participants and worker’s unions. It advocates a rules-based approach to delivering the objects of Digital Transformation which gives due consideration to supporting SMEs and workers with beneficial regulation and standards. It highlights the lessons learned from other sectors which are critical to safeguarding those most likely to be made worse off by a rapidly changing marketplace.

## 6. Conclusions

Digital Transformation is not without risk. To say that an industry as complex as construction is reluctant to embrace change is to dismiss out of hand the thousands of workers and small businesses which gamble on new technologies and upskilling to meet the uncertainties of a rapidly changing marketplace every day.

This research analyzed 59 authoritative articles on Digital Transformation and Industry 4.0 to address the following questions:

I. Since the pandemic, to what extent does Industry 4.0 remain the benchmark for Digital Transformtion?
II. What are the institutional strengths and weaknesses of Industry 4.0 as a platform for Digital Transformation?
III. How has Industry 4.0 research benefitted construction and mining?

Industry 4.0, despite its flaws, offers valuable lessons for industries like construction which must be heeded. Particularly in relation to safeguarding workers and supporting SMEs. Crucially, standards and regulation are key to achieving the objectives of Industry 4.0, yet the academic literature is wanting. Ironically, construction industry academics have been leading the charge to expand the body of knowledge and raise awareness; however, they must waste no time in pursing these poorly understood topics.

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