

Appraising Academic Training of Architecture, Engineering and Construction (AEC) Graduates in Fourth Industrial Revolution Technologies

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Abstract

As the global construction industry undergoes digital transformation, it becomes imperative that graduates of Architecture, Engineering and Construction are well-equipped to cope with the reality of technological disruption. The study examined the extent to which the technologies of the Fourth Industrial Revolution (4IR) were taught to students in the Architecture, Engineering and Construction (AEC) Programmes in the institutions of higher learning across Nigeria. A cross-sectional questionnaire survey was employed for the study. The questionnaire was designed to elicit both quantitative and qualitative data. Data were collected from one hundred and seventy (170) graduates of Architecture, Engineering and Construction undergraduate programmes across universities and polytechnics in Nigeria. The collected data were processed and analysed. Tools employed for the data analysis include Descriptive Tables, Thematic analysis, and the Mann-Whitney test. The results show relatively low levels of academic training acquisition ($0.27 \leq RLA \leq 0.63$) for all of the seventy-six (76) technological dimensions of 4IR. However, entrepreneurship, digital communications and information technology are among the top-rated as knowledge acquired during the respondents' academic training. Also, there was no significant difference in the level of exposure of university and polytechnic graduates of AEC to the technological dimensions of 4IR. The study concludes that the component of 4IR technologies in AEC programmes is low and identifies critical areas requiring intervention by regulatory agencies and the management of tertiary institutions in the review and repositioning of AEC curriculum.

Keywords: Architecture, Construction, Digitalisation, Engineering, Training.

Introduction

The Fourth Industrial Revolution (4IR) was coined by the German government in 2011 to enhance competitiveness in Germany's machine-building industry. (Klinc & Turk, 2019). 4IR represents a digital revolution where the physical, digital, and biological realms converge through technologies such as the Internet of Things, artificial intelligence, cloud computing, and 3-D printing (Ketchiwou & Ngulube, 2025; Li & Yang, 2017; Newman et al., 2021; Wilson, 2025a). The Architecture, Engineering and Construction (AEC) industry has always been an industry that has thrived on innovation and new technologies and methods over the years (Forcael et al., 2020), with recent innovations having a high positive impact by contributing to diverse facets of AEC such as project planning, design, estimating, and site monitoring (Begić & Galić, 2021).

The need to increase productivity and return on investment (ROI) in the AEC industry has become a major concern for industry stakeholders. Poor productivity is being experienced in the AEC industry, with loss of productivity, increased waste, rework, schedule and cost overruns, and allied multiple challenges resulting in hostile relationships between project stakeholders (Osunsanmi et al., 2020). Thus, the AEC industry must renovate and revolutionise itself through digital technologies of the 4IR.

While the relevance of digitalised technologies in AEC has garnered interest across developed countries, there is insufficient understanding regarding strategies for adequate education, training and the implementation of 4IR technologies among AEC professionals in developing countries, particularly in Africa (Osunsanmi et al., 2020). The totality of the extent to which knowledge acquisition on 4IR technologies is advancing in Africa remains obscured, as existing literature, such as Saka and Chan (2019),

and Govender et al. (2018), were limited in focus to investigating awareness levels and the deployment of Building Information Modelling (BIM) technologies on projects, while knowledge acquisition, training, and upskilling in the totality of 4IR components is unknown.

As a crucial first step, it is important to assess the level of academic training that is given to those who have completed various tertiary institution programmes in AEC. This assessment will establish the extent to which AEC graduates have acquired relevant knowledge about 4IR, and it would serve as a basis for exploring strategies for closing the gaps between the present state of knowledge and the expectations for future-ready professionals. Numerous research studies, including those conducted by Adepoju and Aigbavboa (2020), Kozlovskaja et al. (2021), and Maskuriy et al. (2019), have demonstrated a significant interest in the utilisation of 4IR technologies among stakeholders of the AEC sector in developed nations. However, there remains a significant knowledge gap regarding the extent to which graduates of AEC programmes were taught about the technological dimensions of 4IR, particularly in developing countries (Begić & Galić, 2021; Osunsanmi et al., 2020). This has created a gap in the literature on the level of AEC graduates' knowledge acquisition on 4IR components.

Aim and objectives of the study

This study aims to investigate the level of academic training acquired by AEC graduates on 4IR with a view to identifying measures for improved academic training on 4IR. The specific objectives of the study are as follows:

To assess the level of 4IR academic training acquired by AEC graduates of Nigerian Universities and Polytechnics

To identify measures for improving academic training on 4IR in AEC programmes across Nigerian Universities and Polytechnics

Hypothesis of the study

Ho: There is no significant difference between Nigerian Universities and Polytechnics AEC graduates in the level of acquired 4IR academic training.

Literature Review

The word "revolution" implies a fundamental shift in the way people utilise technology and frame the world, with ramifications for social and economic institutions (Tillerias et al., 2020). Revolutions are transformational and disruptive processes that affect and influence several systems. Industrial revolutions, which are characterized as shifts in scientific paradigms, primarily technical ones involving people, have been linked to the development of societies (Pinheiro et al., 2019). Three industrial revolutions have been recognised throughout history and around the globe. These three revolutions have sparked a fourth one, which maximises all of the previously acquired knowledge and frees up room for enormous advances in information technology (Kruger & Steyn, 2025; Olsson et al., 2021; Wilson, 2025a). The primary objective of the first and second industrial revolutions was to raise labour productivity, which was achieved by 500–1000% and was made possible by fundamentally altering manufacturing methods (Zaritskyi & Ponomarenko, 2022). Nevertheless, the first computers were created in the 1930s, but it took decades (from transistors to programming languages and integrated circuits) for them to become more powerful and dependable while still being manageable in size and complexity (Klinc & Turk, 2019). The transitional period was the 1970s, when numerically controlled machines, digital design assistance, and computerisation of serial manufacturing were all introduced. The move from an industrial country to an information society, facilitated in large part by computers, is known as the "digital revolution" (Sharma & Singh, 2020). Through the use of electronics and information technology, the third industrial revolution improved automation (Alaloul et al., 2018).

The third industrial revolution saw the emergence and dominance of electronic gadgets, ushering in this age. It began to knock on our doors when computers first appeared. It encompasses advancements in electronic technology from the first devices created through current (early 21st century) contemporary technologies (Taher, 2021), as businesses progressively integrated electrical and digital technologies into their manufacturing facilities (Marzano & Martinovs, 2020). These devices allowed us to automate blue-collar jobs and factories, and finally, the advent of cyber-physical systems allowed machines to communicate with one another and increase technology-human interaction, ushering in the Fourth Industrial Revolution, or 4IR, as it is also known (Kozlovska et al., 2021). In April 2013, the Hannover Industrial Expo debuted the concept of "4IR," aiming to redefine the industrial landscape by transitioning from centralised production to decentralised production and control. The German government, industry leaders, researchers, organisations, and trade unions spearheaded a unified national strategy. This strategy revolves around cutting-edge technologies that merge virtual networks with physical entities, including the Internet of Things, manufacturing services, and other transformative emerging technologies, ushering in a revolutionary era for industries (Li & Yang, 2017). Several new or enhanced technologies have been integrated to create the phenomenon known as "4IR," which allows new functions and improves on existing ones. It is a transformational process with radical components. 4IR may be a technical trajectory with no turning back at this time (Pinheiro et al., 2019).

4IR aims to personalise and connect products to the internet, enabling product and part tracking, automating adaptable production chains, promoting seamless communication between products, parts, and machines, enhancing human-machine interaction, and empowering IoT-enabled smart factories. It also seeks to augment business models by adding value to production chains. (Jayashree et al., 2021). While gradually permeating various facets of the construction industry, these technologies have significantly contributed to enhancing design efficiency, reducing emissions, evaluating performance, managing resources, conserving energy, monitoring risks, and expediting project delivery in recent years. However, intelligent construction processes are still nascent and are currently trailing behind advancements witnessed in other industries (Yousif et al., 2022). 4IR revolutionizes the global landscape through social and technological transformation (Javaid et al., 2022). According to Haseeb et al. (2019), the implementation of 4IR within the construction industry has proven to be instrumental in surmounting various technical challenges and fostering sustained corporate achievements. By facilitating the generation of novel technological data and establishing streamlined and adaptable value chains, 4IR assumes the crucial responsibility of seamlessly integrating and synergistically amalgamating intelligent machines, human agents, tangible objects, manufacturing assembly lines, and operational workflows across multiple organisational tiers. (Tay et al., 2018).

Therefore, it is of paramount importance for the construction industry, as part of every industry, to embrace the principles and methodologies entailed within the framework of 4IR. By doing so, the sector can unlock significant advancements in productivity across all facets. In essence, 4IR encompasses the forthcoming trajectory of industrial evolution, facilitating the adoption of intelligent manufacturing practices that rely on Cyber-Physical Systems (CPS). In the context of construction, this entails the establishment of Cyber-Physical Production Systems (CPPS), harnessing the power of the Internet of Things (IoT), and effectively implementing and operating smart factories. By seamlessly integrating these cutting-edge technologies, the construction industry can achieve an all-encompassing boost in productivity while paving the way for a more efficient and intelligent future of manufacturing (Hossain & Nadeem, 2019). Previous literature attempts on the transformative impact of the 4IR on industrial and educational landscapes have specifically emphasised the general transition of university education to "University 4.0" models in Africa and globally (Gartoumi & Tekouabou, 2024; Koukaras et al., 2026). The focus of these previous researchers includes the integration of emerging technologies such as Artificial Intelligence (AI), Additive Manufacturing (AM/3D printing), and Building Information Modelling (BIM) into academic training. Also, there has been extensive advocacy for the overhauling of education curriculum at the tertiary education level aimed at

addressing the need for "future-ready skills" by delivering a blend of high technical proficiency (e.g., data analysis, man-machine communication) and flexible management/soft skills (e.g., adaptability, critical thinking, and leadership) to navigate an increasingly digitised world (Hamouda et al., 2025; Klenam et al., 2022; Kruger & Steyn, 2024; Wilson, 2025b).

Despite these efforts, gaps and limitations still exist in the academic training of Architecture, Engineering, and Construction (AEC) graduates, with noticeable widening disparity between the skills currently possessed by graduates and those demanded by the 4IR industry. Especially within Sub-Saharan Africa, current policies and curricula still address technological advancements within a traditional "Industry 3.0" framework, lacking the necessary integration of 4IR considerations. The World Economic Forum (2020) published seventy-six (76) components of 4IR covering frontier technologies, ethics and identity, agile technology governance, agency and trust, disrupting jobs demanding new skills, technology and access inclusion and technology innovation, among others. The study adopts the various components of 4IR as extracted from the literature that were reviewed in the course of the study.

Materials and Methods

A cross-sectional survey was adopted for the study. The population of the study comprises graduates of Nigerian Universities and Polytechnics who studied Architecture, Engineering and Construction-related programmes, respectively. An online survey form was designed and used for the collection of primary data for the study. Cochran's formula for determining sample size was used to determine a representative sample for the study as follows:

$$SS = \frac{Z^2 pq}{e^2} \quad (1)$$

where $z = 1.96$ at 95% confidence level,

$e = 0.05$ at 5% precision level,

$p = 0.07$

$q = 1 - p = 1 - 0.07 = 0.93$.

$$SS = \frac{1.96^2 \times 0.07 \times 0.93}{0.05^2}$$

$SS = 101$

Therefore, a sample size of 101 was obtained with an increment of 20% allowed for anticipated non-response to the online survey. The survey was structured into three parts. Part A focused on eliciting demographic information about the respondents. Part B presented the respondents with the taxonomy of seventy-six (76) components of 4IR for evaluation. The components were collated based on an extensive review of literature. Part C of the survey requested participants to provide suggestions on measures by which academic training in 4IR could be improved. This response column for this section was designed as open-ended to facilitate free expression from the respondents. In ensuring the integrity of the test, both face and content validity were used. Content validity focuses on how well the instrument covers the entire structure, whereas face validity focuses on the overall superficial appearance of the instrument. These were reviewed by two senior lecturers from the Department of Building, University of Lagos. All the corrections and constructive criticisms made by the reviewers were the basis for the final version of the questionnaire. This was done to ensure content validity before administering it to the respondents.

Participation in the survey was voluntary, and informed consent was obtained from all respondents. Respondents were assured of anonymity and confidentiality, and ethical approval was obtained in accordance with institutional research standards. A total of 170 participants completed the online survey. The collected responses were cleaned, coded using Microsoft Excel and thereafter analysed using the Statistical Package for Social Sciences (Version 27). Frequency tables, relative level of acquired academic training index (RLI) and Mann-Whitney test of difference were used as statistical tools for the descriptive

and inferential statistical analyses, respectively. The relative level of acquired academic training index (RLI) score for each of the 4IR components was calculated using the formula (2).

The RLA is calculated as:

$$RLI = \frac{\sum W}{A * N} \quad (2)$$

Where;

W = the weight given to each component by the respondents and ranges from 1 to 5.

A = the highest weight = 5.

N = the total number of respondents (Dube et al., 2022).

The calculated RLI values were interpreted using the scale $RII \geq 0.76$ means very high, $0.67 \leq RII \leq 0.75$ means high, $0.45 \leq RII \leq 0.66$ means low and $RII \leq 0.44$ means very low (Magutu & Kamweru, 2015). The data obtained from open-ended questions of the Survey's Part C was analysed using Thematic analysis to identify patterns and themes and to provide valuable insights on the subject of investigation.

Results and Discussion

Error! Reference source not found. presents the demographic data of the survey participants, such as the participants' gender, category of studied programme, category of institution attended, age, and the year of graduation.

Table 1: Demographic data of respondents

Demography	Frequency	Percent
Gender		
Male	130	76.5
Female	40	23.5
Total	170	100.0
Studied Programme		
Architecture	51	30.0
Construction	75	44.1
Engineering	44	25.9
Total	170	100.0
Institution Category		
University	100	58.8
Polytechnic	70	41.2
Total	170	100.0
Age		
21-30	140	82.4
31-40	25	14.7
Above 40	5	2.9
Total	170	100.0
Year of Graduation		
2010-2015	66	38.8
2016-2020	104	61.2
Total	170	100.0

Table 1 shows that 76.5 percent of the respondents were male, while 23.5 percent were female. This implies that the perceived level of academic training of both the male and female genders who were graduates of AEC was captured by the study. The results equally show that the respondents cut across the various disciplines of Architecture (30 percent), Construction (44.1 percent) and Engineering (25.9 percent) respectively. Furthermore, the two major categories of tertiary institutions in Nigeria, namely the University

and the Polytechnic, had adequate representation of 58.8 percent and 41.2 percent respectively. The result also shows that the dominant age group of the respondents is 21 to 30 years, which accounts for 82.4 percent of the responses. This implies that the respondents are adults and could easily comprehend the survey questions. The result also shows that the majority of the respondents graduated less than 10 years ago, between 2016 and 2020 (61.2 percent), which implies that they graduated not too long ago from their respective institutions and can positively contribute to the survey based on their experience. In addressing the first objective of the study, the respondents were presented with seventy-six components of 4IR for them to assess the level of academic training that they acquired on each of the components in the course of their academic training. A 5-point Likert scale ranging from very low to very high was provided as the rating scale for each of the components. The collected responses were analysed using the relative level of acquired academic training index (RLI) and the results of the analysis for the responses are presented in Figure 1.

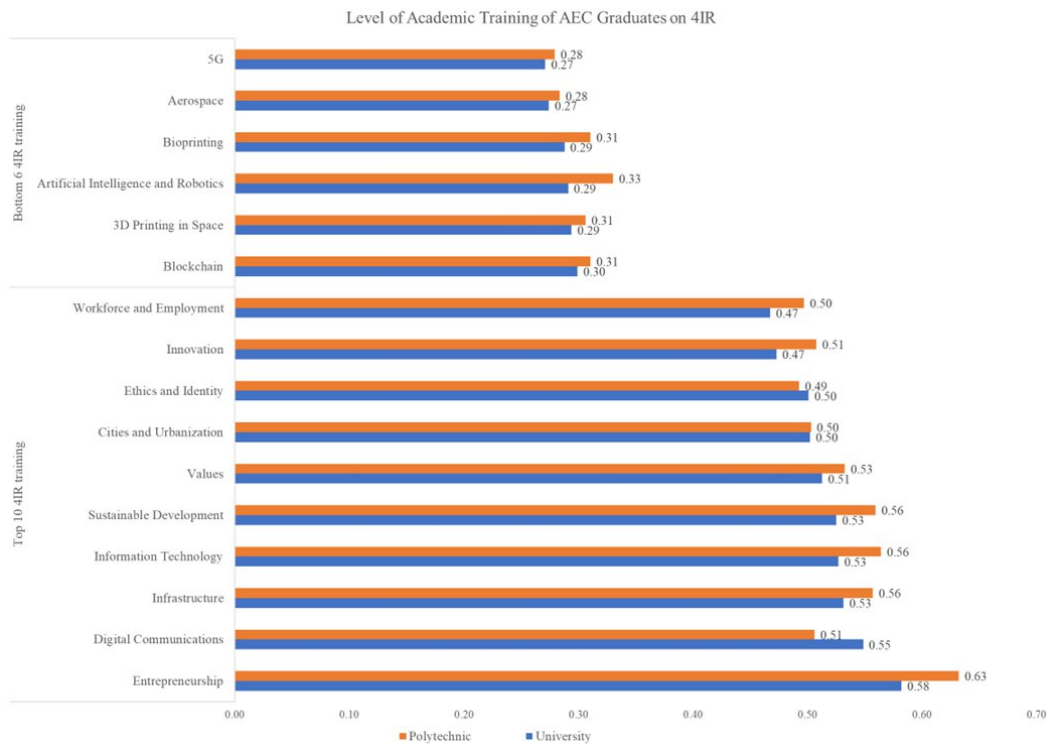


Figure 1: Level of academic training acquired by the respondents

Figure 1 shows the level of academic training that was acquired by the respondents during the course of their programme at a tertiary institution. The result shows the top 10 and bottom 6 of the 76 4IR components that were assessed. The result generally shows that the relative level of academic training in Nigerian universities and polytechnics ranges from average to low levels ($0.27 \leq RLA \leq 0.63$) with slight differences between university and polytechnic graduates across the 4IR components for which they acquired academic training during their academic study. The top-rated components for which AEC graduates acquired academic training include: Entrepreneurship ($0.58 \leq RLA \leq 0.63$) as the first, Digital Communication ($0.51 \leq RLA \leq 0.55$) as the second, Infrastructure, Information Technology and Sustainable Development ($0.53 \leq RLA \leq 0.53$) jointly emerging as third-rated. Comparatively, the result shows that Polytechnics AEC graduates acquired higher academic training in Entrepreneurship (RLI=0.63), Infrastructure (RLI=0.56), Information Technology (RLI=0.56), Sustainable Development (RLI=0.56), Values (RLI=0.53), Innovation (RLI=0.51), and Workforce and Employment (RLI=0.50) while Universities AEC graduates acquired higher academic training in Digital Communication (RLI=0.55), and Ethics and Identity (RLI=0.50).

Table 2: Mann-Whitney test of difference between Nigerian Universities and Polytechnics AEC graduates in the level of acquired 4IR academic training

SN	4IR Components	University		Polytechnic		Mann-Whitney Test Statistics				Decision
		N	Sum of Ranks	N	Sum of Ranks	U	W	Z	<i>p</i>	
1	Entrepreneurship	99	7990.50	69	6205.50	3040.50	7990.50	-1.241	0.21	Ho accepted
2	Digital Communications	97	8385.00	68	5310.00	2964.00	5310.00	-1.140	0.25	Ho accepted
3	Information Technology	93	7188.50	67	5691.50	2817.50	7188.50	-1.056	0.29	Ho accepted
4	Sustainable Development	96	7536.50	64	5343.50	2880.50	7536.50	-0.684	0.49	Ho accepted
5	Infrastructure	93	7215.50	65	5345.50	2844.50	7215.50	-0.645	0.52	Ho accepted
6	Values	94	7540.50	68	5662.50	3075.50	7540.50	-0.421	0.67	Ho accepted
7	Cities and Urbanisation	96	7801.00	66	5402.00	3145.00	7801.00	-0.081	0.94	Ho accepted
8	Ethics and Identity	97	8039.50	67	5490.50	3212.50	5490.50	-0.127	0.90	Ho accepted
9	Innovation	96	7605.00	67	5761.00	2949.00	7605.00	-0.930	0.35	Ho accepted
10	Workforce and Employment	95	7522.00	66	5519.00	2962.00	7522.00	-0.617	0.54	Ho accepted
11	Arts and Culture	99	7825.50	68	6202.50	2875.50	7825.50	-1.660	0.10	Ho accepted

Note: *p* is significant at $*p \leq 0.05$

The result in Table 2 shows that the level of acquired academic training in 4IR components between Universities and Polytechnics AEC graduates is not significantly different, $-0.081 \leq Z \leq -1.684$, $0.10 \leq p \leq 0.90$, hence, the null hypothesis is accepted for each of the 4IR components. This implies that there is no significant difference in the level of acquired 4IR academic training between Nigerian Universities and Polytechnics AEC graduates.

Discussion of Findings

The results show that there is a very low level of acquired 4IR academic training among AEC graduates of Nigerian Universities and polytechnics, respectively. This concurs with Maskuriy et al. (2019) that the emerging technological skills among professionals in the Architecture, Engineering, and Construction fields are extremely low. The results also support Kozlovska et al., (2021), that professionals in AEC have limited early exposure to new technology during their academic training. The results further buttress the position of Adepoju and Aigbavboa (2020), who explain that information technology and digital communications, especially with respect to Building Information Modelling (BIM), seem to be receiving ample attention among the numerous emerging technologies that are available for the construction industry. Furthermore, the results show the need for a review of the curriculum of AEC programmes in Nigerian Universities and Polytechnics to reflect the skill set required for the future of work in the industry. This support Zabidin and Belayathum (2019) that tertiary institutions must address the present gaps in acquiring academic training on the various modern technologies for improving efficiency at the workplace through the revamping of existing learning course materials. The results also emphasize the call of Kozlovska et al., (2021) and Wilson (2025) on the need for soft and practical skills integration in the curriculum framework of tertiary institutions as a means of producing graduates with balanced capabilities, diversity, and flexibility to thrive in a competitive labour market.

Conclusion

Premised on the findings, the study concludes that the level of Fourth Industrial Revolution (4IR) academic training acquired by Architecture, Engineering and Construction (AEC) graduates of Nigerian Universities and Polytechnics is very low, with eighty-three (83) percent of the 4IR components not acquired through academic training. Also, the level of acquired 4IR academic training between Nigerian University and Polytechnic graduates who studied Architecture, Engineering and Construction-related programmes are relatively the same. The study recommends that the curriculum of Architecture, Engineering and Construction programmes be restructured to meet the needs of an evolving world so as to make the graduates future-ready. The National Universities Commission (NUC) and the National Board for Technical Education (NBTE) should promote policy interventions aimed at improved digital skills acquisition. These apex regulatory bodies for tertiary education in Nigeria should also work with the various AEC regulating bodies such as ARCON, COREN, and CORBON who are the primary statutory regulatory bodies governing the AEC practices and are tasked with licensing professionals, standardizing practices, and enforcing professional codes of conduct across architecture, engineering, and building construction to review and close gaps in 4IR skills acquisition across the nation's tertiary institutions.

In addition, facilities for promoting 4IR should be readily provided in tertiary institutions by the government and thereafter, training and retraining of lecturers on 4IR should be encouraged with adequate motivation. Practical sessions on 4IR should equally be incorporated into the academic training of Architecture, Engineering and Construction to further drive home the concepts and principles of 4IR. Finally, interdisciplinary collaborations should be encouraged between staff and students of Architecture, Engineering and Construction and those in technology-related disciplines, as this would enhance knowledge exchange and accelerate the level of skills acquisition in emerging technologies.

References

- Adepoju, O. O., & Aigbavboa, C. O. (2020). Implementation of Construction 4.0 in Nigeria: Evaluating the Opportunities and Threats on the Workforce. *Academic Journal of Interdisciplinary Studies*, 9(5), 254–264. <https://doi.org/10.36941/ajis-2020-0102>
- Al-lami, G. T. (2021). *Industrial Revolution 4 . 0 in the Construction Industry: Challenges and Opportunities*. December.
- Alaloul, W. S., Liew, M. S., Zawawi, N. A. W., & Mohammed, B. S. (2018). Industry Revolution IR 4.0: Future Opportunities and Challenges in Construction Industry. *MATEC Web of Conferences*, 203, 1–7. <https://doi.org/10.1051/mateconf/201820302010>
- Begić, H., & Galić, M. (2021). A systematic review of construction 4.0 in the context of the BIM 4.0 premise. *Buildings*, 11(8). <https://doi.org/10.3390/BUILDINGS11080337>
- Dube, M. N., Wankhade, P. R. R., & Sabhuiuddin, S. (2022). Relative Importance Index (RII) for Effective Evaluation of Construction Subcontracting Practices. *International Journal of Research Publication and Reviews*, 3(7), 37–41.
- Forcael, E., Ferrari, I., Opazo-Vega, A., & Pulido-Arcas, J. A. (2020). Construction 4.0: A literature review. In *Sustainability (Switzerland)* (Vol. 12, Issue 22, pp. 1–28). MDPI. <https://doi.org/10.3390/su12229755>
- Gartoumi, K. I., & Tekouabou, S. C. K. (2024). Exploring African skills 4.0 required for 4IR industry: a systematic literature review. *Data and Policy*, 6. <https://doi.org/10.1017/dap.2024.28>
- Govender, K., Nyagwachi, J., Smallwood, J. J., & Allen, C. J. (2018). The awareness of integrated project delivery and building information modelling - facilitating construction projects. *International Journal of Sustainable Development and Planning*, 13(1), 121–129. <https://doi.org/10.2495/SDP-V13-N1-121-129>
- Hamouda, S., Marshall, L., Sanders, K., Tshukudu, E., Adelakun-Adeyemo, O., Becker, B. A., Dodoo, E. R., Korsah, G. A., Luvhengo, S., Ola, O., Parkinson, J., & Sanusi, I. T. (2025). Computing Education in African Countries: A Literature Review and Contextualised Learning Materials. In *Annual*

- Conference on Innovation and Technology in Computer Science Education, ITiCSE* (Vol. 1, Issue 1). Association for Computing Machinery. <https://doi.org/10.1145/3689187.3709606>
- Haseeb, M., Hussain, H. I., Ślusarczyk, B., & Jermstipparsert, K. (2019). Industry 4.0: A solution towards technology challenges of sustainable business performance. *Social Sciences*, 8(5). <https://doi.org/10.3390/socsci8050154>
- Hossain, M. A., & Nadeem, A. (2019). Towards digitizing the construction industry: State of the art of construction 4.0. *ISEC 2019 - 10th International Structural Engineering and Construction Conference*, 1–6. <https://doi.org/10.14455/isec.res.2019.184>
- Javaid, M., Haleem, A., Singh, R. P., Suman, R., & Gonzalez, E. S. (2022). Understanding the adoption of Industry 4.0 technologies in improving environmental sustainability. *Sustainable Operations and Computers*, 3(May 2021), 203–217. <https://doi.org/10.1016/j.susoc.2022.01.008>
- Jayashree, S., Hassan Reza, M. N., Malarvizhi, C. A. N., Maheswari, H., Hosseini, Z., & Kasim, A. (2021). Article the impact of technological innovation on industry 4.0 implementation and sustainability: An empirical study on malaysian small and medium sized enterprises. *Sustainability (Switzerland)*, 13(18). <https://doi.org/10.3390/su131810115>
- Ketchiwou, G. F., & Ngulube, P. (2025). Empowering African women with the skills required in the workplace in the Fourth Industrial Revolution (4IR). *The Thinker*, 105(4), 33–48. <https://doi.org/10.36615/5VCSC132>
- Klenam, D. E. P., Bamisaye, O. S., Williams, I. E., Van Der Merwe, J. W., & Bodunrin, M. O. (2022). Global perspective and African outlook on additive manufacturing research - an overview. *Manufacturing Review*, 9, 128–131. <https://doi.org/10.1051/mfreview/2022033>
- Klinc, R., & Turk, Ž. (2019). Construction 4.0 – Digital Transformation of One of the Oldest Industries. *Economic and Business Review*, 21(3). <https://doi.org/10.15458/ebv.92>
- Koukaras, C., Stavrinides, S. G., Hatzikraniotis, E., Mitsiaki, M., Koukaras, P., & Tjortjis, C. (2026). Navigating the Future of Education: A Review on Telecommunications and AI Technologies, Ethical Implications, and Equity Challenges. *Telecom*, 7(1), 2. <https://doi.org/10.3390/telecom7010002>
- Kozlovskaja, M., Klosova, D., & Strukova, Z. (2021). Impact of industry 4.0 platform on the formation of construction 4.0 concept: A literature review. In *Sustainability (Switzerland)* (Vol. 13, Issue 5, pp. 1–15). <https://doi.org/10.3390/su13052683>
- Kruger, S., & Steyn, A. A. (2024). Navigating the fourth industrial revolution: a systematic review of technology adoption model trends. *Journal of Science and Technology Policy Management*, 16(10), 24–56. <https://doi.org/10.1108/JSTPM-11-2022-0188>
- Kruger, S., & Steyn, A. A. (2025). Navigating the fourth industrial revolution: a systematic review of technology adoption model trends. *Journal of Science and Technology Policy Management*, 16(10), 24–56. <https://doi.org/10.1108/JSTPM-11-2022-0188>
- Li, J., & Yang, H. (2017). A research on development of construction industrialization based on BIM technology under the background of industry 4.0. *MATEC Web of Conferences*, 100. <https://doi.org/10.1051/mateconf/201710002046>
- Magutu, J., & Kamweru, K. (2015). The Phenomenon of Building Maintenance Culture : Need for Enabling Systems The Crisis of Building Maintenance in Kenya. *Global Journal of Engineering, Design & Technology*, 4(5), 8–12.
- Marzano, G., & Martinovs, A. (2020). Teaching Industry 4.0. *SOCIETY. INTEGRATION. EDUCATION. Proceedings of the International Scientific Conference*, 2(May), 69. <https://doi.org/10.17770/sie2020vol2.4833>
- Maskuriy, R., Selamat, A., Ali, K. N., Maresova, P., & Krejcar, O. (2019). Industry 4.0 for the construction industry-How ready is the industry? *Applied Sciences (Switzerland)*, 9(14). <https://doi.org/10.3390/app9142819>
- Newman, C., Edwards, D., Martek, I., Lai, J., Thwala, W. D., & Rillie, I. (2021). Industry 4.0 deployment in the construction industry: a bibliometric literature review and UK-based case study. *Smart and*

- Sustainable Built Environment*, 10(4), 557–580. <https://doi.org/10.1108/SASBE-02-2020-0016>
- Olsson, N. O. E., Arica, E., Woods, R., & Madrid, J. A. (2021). Industry 4.0 in a project context: Introducing 3D printing in construction projects. *Project Leadership and Society*, 2(September 2020), 100033. <https://doi.org/10.1016/j.plas.2021.100033>
- Osunsanmi, T. O., Aigbavboa, C. O., Emmanuel Oke, A., & Liphadzi, M. (2020). Appraisal of stakeholders' willingness to adopt construction 4.0 technologies for construction projects. *Built Environment Project and Asset Management*, 10(4), 547–565. <https://doi.org/10.1108/BEPAM-12-2018-0159>
- Pinheiro, P., Putnik, G. D., Castro, A., Castro, H., Fontana, R. D. B., & Romero, F. (2019). Industry 4.0 and industrial revolutions: An assessment based on complexity. *FME Transactions*, 47(4), 831–840. <https://doi.org/10.5937/fmet1904831P>
- Saka, A. B., & Chan, D. W. M. (2019). A scientometric review and metanalysis of building information modelling (BIM) research in Africa. *Buildings*, 9(4). <https://doi.org/10.3390/buildings9040085>
- Sharma, A., & Singh, B. J. (2020). Evolution of Industrial Revolutions: A Review. *International Journal of Innovative Technology and Exploring Engineering*, 9(11), 66–73. <https://doi.org/10.35940/ijitee.i7144.0991120>
- Tay, S. I., Lee, T. C., Hamid, N. Z. A., & Ahmad, A. N. A. (2018). An overview of industry 4.0: Definition, components, and government initiatives. *Journal of Advanced Research in Dynamical and Control Systems*, 10(14), 1379–1387.
- Tilleras, H., Segura, J., & Álvarez, G. (2020). Innovation, Evolution and History of Technology in Industry. *Athenea*, 1(1), 14–21. <https://doi.org/10.47460/athenea.v1i1.2>
- Waziri, B. S. (2016). Design and construction defects influencing residential building maintenance in Nigeria. *Jordan Journal of Civil Engineering*, 10(3), 313–323.
- Waziri, B. S., & Vanduhe, B. A. (2013). Evaluation of Factors Affecting Residential Building Maintenance in Nigeria : Users ' Perspective. *Civil and Environmental Research*, 3(8), 19–25.
- Wilson, R. (2025a). What is 4IR or Industry 4.0, and how will it impact Learning Development? *Journal of Learning Development in Higher Education*, 37. <https://doi.org/10.47408/JLDHE.VI37.1757>
- Wilson, R. (2025b). What is 4IR or Industry 4.0, and how will it impact Learning Development? *Journal of Learning Development in Higher Education*, 37. <https://doi.org/10.47408/jldhe.vi37.1757>
- World Economic Forum. (2020). Infrastructure 4.0: Achieving Better Outcomes with Technology and Systems Thinking. In *World Economic Forum*.
- Yousif, O. S., Zakaria, R., Wahi, N., Aminudin, E., Hamimi, A., & Tharim, A. (2022). International Journal of Sustainable Development and Planning Monitoring the Construction Industry Towards a Construction Revolution 4 . 0. *Planning*, 17(2), 633–641.
- Zabidin, N. S., Belayutham, S., Khairil, C., & Che, I. (2019). *A Bibliometric Analysis of Industrial Revolution (IR) 4 . 0 in Construction Engineering Education*. 6, 2–6.
- Zaritskyi, O., & Ponomarenko, O. (2022). Technology in the Industrial Revolutions and Its Impact on the Key Performance Indicators of Organizations. *CEUR Workshop Proceedings*, 3149(January), 87–96.