XVI International Conference on Durability of Building Materials and Components
DBMC 2023, China
K.F. Li and D.P. Fang (Eds)

State-of-Art of Construction 4.0: An Academia Vs Industry Comparative Study

Wasiq Ahmad[1] **and Salman Azhar**[1]

[1] McWhorter School of Building Science, Auburn University, Auburn, Alabama 36849, USA
wza0023@auburn.edu, sza0001@auburn.edu (Corresponding author)

Abstract. *The manufacturing industry is experiencing the 4th Industrial Revolution, also known as Industry 4.0. It encapsulates cyber-physical systems (i.e., combining sensing, computation, control and networking into physical objects and infrastructure) integrated towards digitalization and automation of the manufacturing sector. The construction industry has also benefited from these technologies, which go by Construction 4.0. Despite the construction industry often being blamed for its reluctance to implement emerging technologies and non-traditional management methods, recent research attempted to integrate Industry 4.0 emerging technologies to keep up with the manufacturing sector. This shows that academia and industry need each other's hand-in-hand support in order to implement these technological advances. This study investigates the status of Construction 4.0 technologies adoption in academia and industry in the United States of America (USA) and measures the level of collaboration. Relevant data is collected via web-based questionnaire surveys that are distributed to academia and industry professionals within the USA to inquire about the status of construction 4.0 technologies and their adoption rate. The collected data are analyzed and important findings are reported in this paper. The results show that around 61% of the professionals from academia and 33% from industry are fully or somehow familiar with the term – 'Construction 4.0'. There has been significant adoption of BIM, laser scanners, and drones in each sector. The rest of the technologies show potential in upcoming years, and academia and industry have methods in place of updating the workforce on new technologies. However, a lack of collaboration has been observed as 50% of the respondents reported no ongoing or past research projects between academia and industry in this domain. It is hoped that the findings of this research will help both academia and industry to join forces to modernize the construction industry.*

Keywords: *Construction 4.0, Industry 4.0, Digital Construction, Digitalization, Construction Technologies, Collaboration.*

1 Introduction

The manufacturing industry is currently experiencing the 4th Industrial Revolution, which is also known as Industry 4.0 (Manda and Ben Dhaou 2019). It encapsulates cyber-physical systems (i.e., combining sensing, computation, control and networking into physical objects and infrastructure) integrated towards digitalization and automation of the manufacturing sector. The construction industry has also benefited from these technologies which goes by the term - *Construction 4.0*. The origin of the term *Construction 4.0* dates back to 2016 when it first appeared (Berger 2016) and ever since then several researchers have tried to define it at various instances. Before getting to the definition of this term, first, let's explore the other terminologies that go by different names but refer to similar concept that of Construction 4.0. Since this term did not originate alone but adopted the theoretical framework of a much broader concept: Industry 4.0, that's why it is often referred to as "*Industry 4.0 in Construction*

Industry"(Nowotarski and Paslawski 2017, Maskuriy et al. 2019, Turner et al. 2021). It is also referred as *"4th generation construction revolution"* (Rastogi 2019).

The concept of Construction 4.0 is at its rudimentary stages and researchers are still trying to come up with a proper definition of what is included in it. It is important to realize that Construction 4.0 is not just construction with technological advancements but a new form of executing construction under the umbrella of innovation and increased productivity (Forcael et al. 2020). Therefore, (Forcael et al. 2020) defined it as a combination of two aspects: (1) Digitalization of construction industry; and (2) Industrialization of construction processes. Digitalization encompasses the use of information using hardware and software. This includes the very simple task of using smartphones on the jobsite for communication purposes or very complex tasks like fetching relevant information for maintenance of facilities using mixed reality equipment. On the other hand, the industrialization of building processes is focused on automation of construction processes. This encapsulates the concept of digital fabrication, modular construction, and off-site prefabrication construction.

In the realm of construction 4.0 and its related technologies, rapid progress has been made in academia regarding its research but little has been transferred to the industry (Forcael et al. 2020). Despite the construction industry often being blamed for its reluctance to implement emerging technologies and non-traditional management methods, some recent researches attempted to integrate Industry 4.0 emerging technologies to keep up the pace with the manufacturing sector (Bhoir and Esmaeili 2015, Bademosi and Issa 2021). This shows that academia and industry need each other's hand-in-hand support in order to implement these technological advances. The labor force statistics from the 2019 American Community Survey show that the share of labor working under the age of 25 has reached 10.8% in 2019 in the construction sector compared to 9.7% in 2015 (U.S. Census Bureau website 2021). This is evident that more younger people are thriving to enter the industry, but it is crucial to understand whether the youth pursuing their construction degrees in academia is equipped with the latest technological knowledge, tools and skills needed to enter the world of Construction 4.0.

Even though the research gap between the construction 4.0 and its adoption is getting narrower, still there is a long way until it is implemented across the lifecycle of the construction projects from early design to operations and maintenance phase. So, it is important to assess where the industry and academia stand in holding the latest advancements that are currently happening. This study investigates the status of Construction 4.0 technologies adoption in academia and industry, measures the level of collaboration, and recommends a path forward.

1.1 Aim and Objectives

The overarching aim of this research is to investigate the status of Construction 4.0 technologies adoption in academia and industry and measure the level of collaboration among them to ensure that the youth-force entering the industry is well equipped with the latest technological knowledge, tools and skills needed in the world of Construction 4.0. The research objectives are as follows: (1) To investigate how the curriculums of different construction programs in the USA are designed in the light of Construction 4.0 technologies education, (2) To analyze the status of Construction 4.0 technologies adoption by construction companies and what improvements have been achieved due to their adoption, (3) To assess the impact of Construction 4.0 research on academic and industry professionals and practices.

2 Literature Review

Since the advent of Industry 4.0 in the construction industry, the technologies associated with it have altered the construction processes at all phases of construction value chain (Oesterreich and Teuteberg 2016). The concept of integrating Industry 4.0 technologies in construction dates back to 2009 but it was not until 2016 when (Oesterreich and Teuteberg 2016) actually referred to this concept as 'Construction 4.0' in their research article. During the era of Industry 4.0, it is hard to explain what exactly Construction 4.0 means (Boton et al. 2021). While some authors (Karmakar and Delhi 2021, Sawhney et al. 2020) say it is the adaption and convergence to digitalization and automation via Industry 4.0 technologies, others define it as developing various technologies for sustainable construction (Jazzar et al. 2020).

2.1 Technologies Associated with Construction 4.0

Systematic literature reviews in Construction 4.0 show that the BIM plays a central role in digital transformation and hides a forest of technological applications behind it (Boton et al. 2021; Bourgault et al. 2020). Different authors have identified different construction 4.0 technologies. Upon analysis, it can be clearly seen in Table 1 that many mentioned technologies are the same. So, that's why a normalization technique is used to categorize similar technologies with different names. For example, 'Drones' and 'Unmanned Aerial Vehicles (UAVs)' fall under Drones. Similarly, 'Big Data' and Big Data Analytics' falls under Big Data.

Table 1. Matrix Table for Construction 4.0 Technologies.

		AUTHORS				
		(Boton et al., 2021)	(Karmakar & Delhi, 2021)	(Bourgault et al., 2020)	(Sawhney et al., 2020)	(Jazzar et al., 2020)
TECHNOLOGIES	Building Information Modeling			✓	✓	✓
	3D Printing	✓				✓
	Additive Manufacturing	✓	✓		✓	
	Augmented Reality (AR)	✓	✓		✓	✓
	Virtual Reality (VR)	✓	✓		✓	✓
	Radio Frequency Identification	✓	✓			
	Internet of Things (IoT)	✓	✓		✓	
	Cloud Computing	✓	✓			
	Artificial Intelligence (AI)		✓	✓	✓	✓
	Cyber Physical Systems	✓			✓	
	Unmanned Aerial Vehicles (UAVs)/ Drons		✓		✓	✓
	Laser Scanning		✓		✓	
	Big Data	✓	✓	✓	✓	
	Robotics				✓	✓
	Blockchain		✓		✓	

2.2 Current Status of Construction 4.0 in Industry

The adoption of Construction 4.0 technologies has far-reaching implications for the whole construction industry, the involved companies, the environment and for the employees. The state of the art of Construction 4.0 technologies are on different levels of maturity (Oesterreich and Teuteberg 2016). Several technologies have reached market maturity and thus are currently available (e.g., BIM, Cloud Computing, Mobile Computing, Modularization). Similarly, a few technologies are still at the formative stage, as prototypes and applications are being developed for mainstream use (e.g., Additive Manufacturing, Augmented, Virtual and Mixed Reality). Despite the given maturity and availability of many technologies, their widespread adoption by construction companies has not taken place until now. In a latest survey report "Digitalization in Construction Report 2022" by RICS shows that apart from the well-established needs of the sector, there is an inclination starting to develop towards using digitalization in construction around the themes of environmental, social and governance (ECG). The (RICS 2022) study shows that 68% companies agree that digitalization processes and practices have not only improved the cost estimation and prediction in their organization but also helped them enhance the progress monitoring systems and the health of their projects.

2.3 Current Status of Construction 4.0 in Academia

It has been observed that construction 4.0 is set to be driven by Data Management across the lifecycle of the project (Karmakar and Delhi 2021). Research in Construction 4.0 technologies are mainly used for *Locate* and *Simulate* actions during the pre-construction (design and engineering) and construction phase of the project (Bourgault et al. 2020). Moreover, it mainly focuses on quality management, risk management and health & safety management processes (Bourgault et al. 2020). On the other hand, (Hossain & Nadeem 2019) proposed a framework to implement the concept of Construction 4.0 and provided a step-by-step procedure to execute it. Similarly, another study, (Jazzar et al. 2020) identified four-layer implementation process for Construction 4.0 which includes, (1) Understanding of Construction 4.0 technologies, (2) Integration of Construction 4.0 technologies across the project lifecycle, (3) Integration of seven previously identified Construction 4.0 technologies, and (4) Requirements that the construction companies must consider.

3 Research Design and Methodology

The research study focuses on two types of target populations, the academia, and the construction industry. Regarding industry, the population comprises of construction professionals working/employed in the Virtual Design and Construction (VDC) departments of construction companies in the USA. Concerning academia; the population comprises of faculty members employed in the construction schools throughout the USA. Because the study topic is specific, the sample population selected for the survey should have prior knowledge and understanding of the topic under discussion. Therefore, the non-probabilistic judgment sampling method was adopted for both industry and academia surveys for more accurate and reliable results. The design of this research consists of two steps. Step one includes the distribution of questionnaires to different industry and academic professionals within the USA, that inquired about the status of construction 4.0 technologies and their adoption rate. For qualitative data collection, questions are designed to get industry and academic professionals' viewpoints regarding the construction 4.0 concept and how both could collaborate to embed these technologies on their jobsite (for industry professionals) and curriculum (for academic professionals). Step 2 leads to the analysis of collected data and figuring out important trends.

4 Main Findings and Discussion

After distributing both surveys, responses were collected over four weeks. Initially, 43 responses were collected from academia survey and 50 from the industry survey. The responses were then compiled and screened based on their completion status, and few incomplete responses were excluded from the study. The results are compartmentalized into two sections, (1) academia; and (2) industry, with their respective discussions in the following sections.

4.1 Academia

The result of the quantitative review shows that around 61% of the respondents from academia are fully or somehow familiar with the term – ‘Construction 4.0’. Almost half of the professionals still do not know or are not familiar with this term in the USA. Upon further questioning, many academic programs indicated their desire to introduce the technologies in the curriculum. The respondents were given the option of choosing the technology and its method of introduction. The method of introduction was ‘Core Courses’, ‘Electives (Independent)’, ‘Part of the core course’, and ‘Part of the elective course’. Nearly 89% of the respondents indicated BIM as a core course. An interesting finding is that most schools are willing to teach these technologies as ‘Part of the core course’, with Laser Scanning and Drones being the foremost technologies in this scenario (Figure 1).

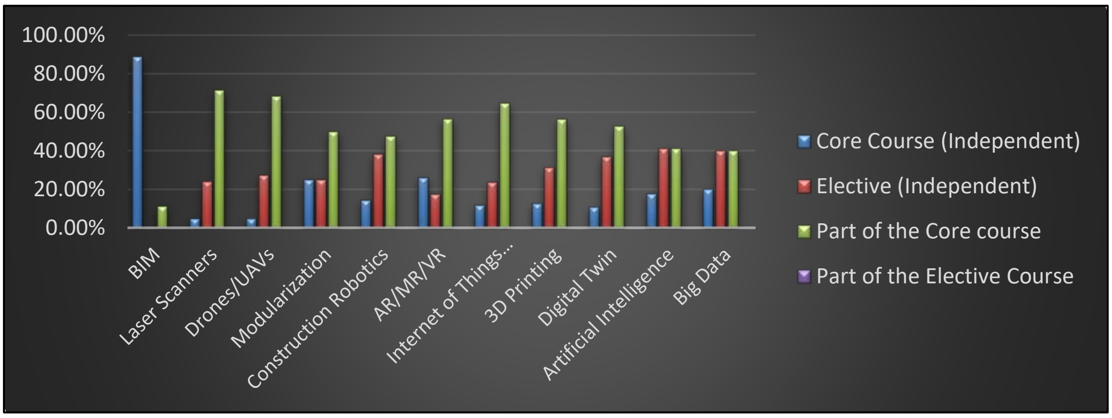

Figure 1. Introduction of new technologies in academia in the future.

The academics were inquired about the level of collaboration between the industry and academia. The judgment criterion to measure the level of collaboration was the number of ongoing industry-funded Construction 4.0-related research projects. Ten (10) out of 20 participants (50%) indicated that there is one or more than one project going on in their department related to Construction 4.0. The results are summarized in Figure 2. Despite the moderate collaboration, academia is positive about industry’s technology adoption. However, the trend seems to drop as we move from BIM to Big Data as can be seen in Figure 3.

4.1.1 Discussion

The results show a promising rise in technology teaching and involvement in the coming years. Since most academics are aware of the concept, it is about time that these technologies will be an inseparable part of future construction curriculums, either through core courses or separate electives. Either way, the inclusion of these technologies looks inevitable. Even though these technologies are taught as part of the undergraduate courses, most graduate programs still lack the inclusion of these technologies into their curriculums. With 50% of respondents reporting no ongoing research, the collaboration between academia and industry is yet to be covered and improved by reducing the socio-economic barriers.

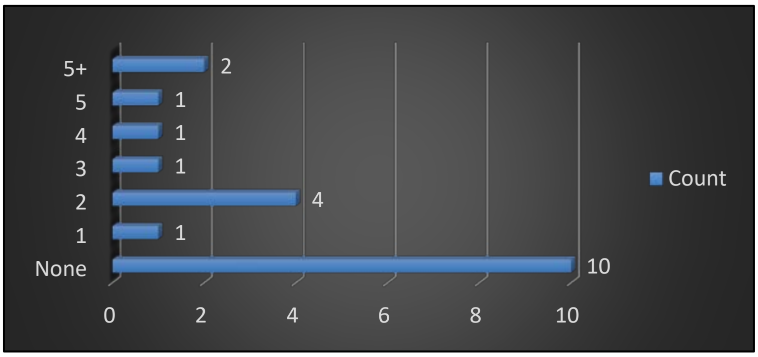

Figure 2. Number of ongoing industry-funded projects.

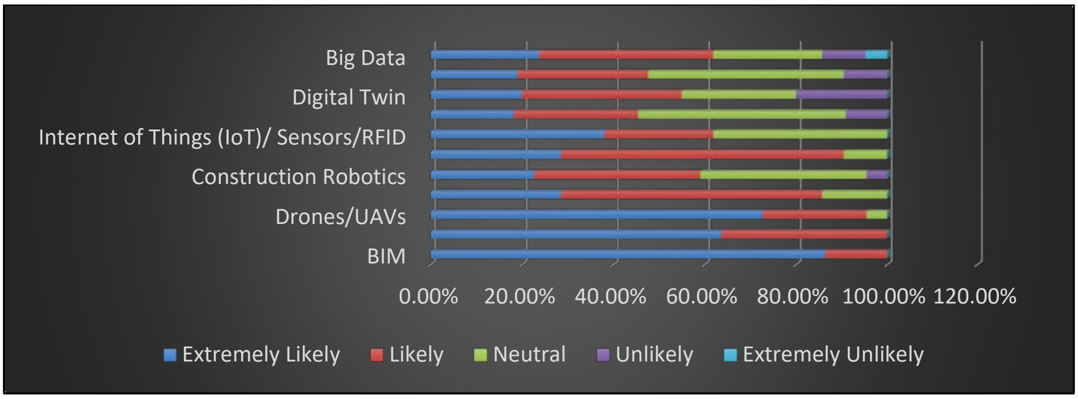

Figure 3. Extent to which industry is willing to Adopt Construction 4.0.

4.2 Industry

The result of the quantitative review shows that around 77% of the professionals in the industry are not familiar with the term – ‘Construction 4.0’. Almost one-quarter of the professionals only know or are familiar with this term in the USA. This clearly shows a stark difference in awareness stats among the academic and industry professionals. Not to mention the high number of professionals indicating BIM as a well-equipped technology and how the workforce entering the industry is well prepared to take on BIM-related challenges. Other than that, the data revolves around moderately and slightly prepared options for the rest of the technologies, which can be seen in Figure 4. Several respondents have also expressed no preparation at all (Figure 4). Hence, the results for the number of ongoing projects stated by different respondents were also low. Figure 5 explains that only three respondents reported 5+ projects, and 14 (61%) reported no ongoing projects.

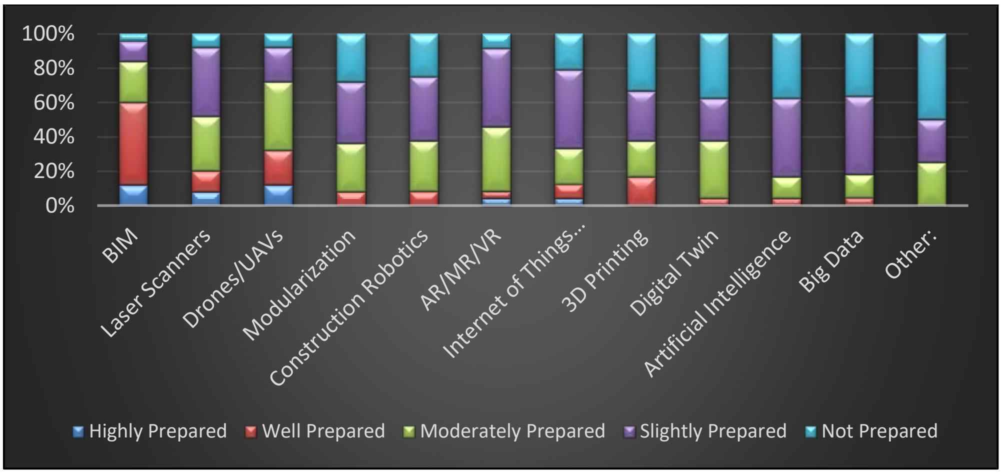

Figure 4. Workforce preparation regarding Construction 4.0 technologies.

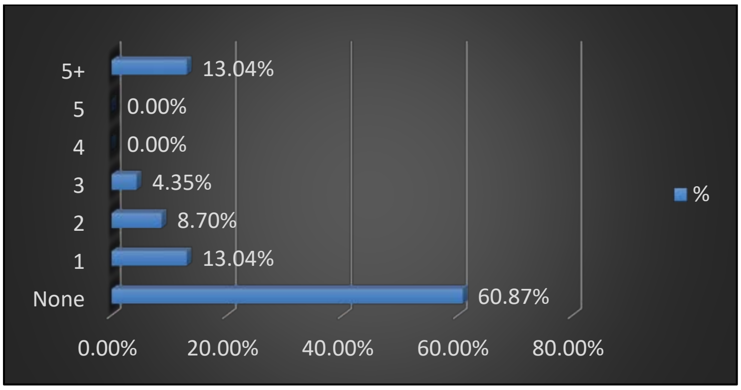

Figure 5. Number of ongoing research projects.

4.2.1 Discussion

The summary of the findings from the industry are listed as follows: (1) Lack of awareness in the industry regarding the Construction 4.0 concept as 77% of the respondents were unaware of the concept, (2) Although the industry is unfamiliar with the concept, specific technologies, which include BIM, laser scanning, and drones, are most frequently employed by the industry. However, the industry has mixed opinions regarding Drones and IoT as the ROI is more spread from 1% to 100%, (3) Low collaboration between industry and academia has been observed.

5 Conclusion and Recommendations

It is fair to say that both academic and industry professionals agreed that the role of the workforce has significantly evolved and changed due to recent technological advancements. The results from academia and industry show similar trends and conclude that there is still potential for improvements in future workforce development. The industry professionals are generally unsure about the workforce and their preparation considering all the Construction 4.0-related technologies. Nevertheless, the industry professionals indicated how highly or well prepared the entering workforce is regarding BIM. Regarding Laser Scanners and Drones, there seems to be a consensus over slightly to moderately prepared. It is evident from the low number of ongoing and past research projects that there is a significant gap between the two hemispheres – academia and industry. In order to form a complete sphere, more collaboration is needed to seek solutions based on technological advancements. However, a trend of adoption can be seen, especially with BIM, which now seems like an integral part of academia and industry. It is being taught in a vast majority of construction education programs and used by many companies throughout the USA. On similar lines, it is hoped that other Construction 4.0 technologies will pave their way in both academia and industry in the coming years.

References

Bademosi, F., & Issa, R. R. A. (2021). *Factors Influencing Adoption and Integration of Construction Robotics and Automation Technology in the US*. Journal of Construction Engineering and Management, 147(8), 04021075. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002103.

Berger, R. (2016). *Digitization in the Construction Industry: Building Europe's Road to "Construction 4.0*. Roland Berger GMBH.

Bhoir, S., & Esmaeili, B. (2015). *State-of-the-Art Review of Virtual Reality Environment Applications in Construction Safety*. 457–468. https://doi.org/10.1061/9780784479070.040.

Boton, C., Rivest, L., Ghnaya, O., & Chouchen, M. (2021). *What is at the Root of Construction 4.0: A systematic review of the recent research effort*. Archives of Computational Methods in Engineering, 28(4), 2331–2350.

Bourgault, M., Danjou, C., & Pellerin, R. (2020). *Construction 4.0: A Survey of Research Trends*.

Forcael, E., Ferrari, I., Opazo-Vega, A., & Pulido-Arcas, J. A. (2020). *Construction 4.0: A Literature Review*. Sustainability, 12(22), Article 22. https://doi.org/10.3390/su12229755.

Hossain, M. A., & Nadeem, A. (2019). *Towards digitizing the construction industry: State of the art of construction 4.0.* 10th International Structural Engineering and Construction Conference, ISEC 2019, May 20, 2019 - May 25, 2019, American Concrete Institute; American Institute of Steel Construction; Architectural Institute of Japan; Japan Concrete Institute; Japan Society of Civil Engineers. https://doi.org/10.14455/isec.res.2019.184

Jazzar, M. E., Urban, H., Schranz, C., & Nassereddine, H. (2020). *Construction 4.0: A roadmap to shaping the future of construction*. 37th International Symposium on Automation and Robotics in Construction: From Demonstration to Practical Use - To New Stage of Construction Robot, ISARC 2020, October 27, 2020 - October 28, 2020, 1314–1321.

Karmakar, A., & Delhi, V. S. K. (2021). *Construction 4.0: What we know and where we are headed?* Journal of Information Technology in Construction, 26, 526–545. https://doi.org/10.36680/j.itcon.2021.028.

Manda, M. I., & Ben Dhaou, S. (2019). *Responding to the challenges and opportunities in the 4th Industrial revolution in developing countries*. Proceedings of the 12th International Conference on Theory and Practice of Electronic Governance, 244–253. https://doi.org/10.1145/3326365.3326398.

Maskuriy, R., Selamat, A., Maresova, P., Krejcar, O., & David, O. O. (2019). I*ndustry 4.0 for the Construction Industry: Review of Management Perspective*. Economies, 7(3), https://doi.org/10.3390/economies7030068.

Nowotarski, P., & Paslawski, J. (2017). *Industry 4.0 Concept Introduction into Construction SMEs.* IOP Conference Series: Materials Science and Engineering, 245, 052043. https://doi.org/10.1088/1757-899X/245/5/052043

Oesterreich, T. D., & Teuteberg, F. (2016). *Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry*. Computers in Industry, 83, 121–139.

Rastogi, S. (2017). *Construction 4.0: The 4th generation revolution*. In *Indian lean construction conference–ILCC 2017*.

RICS. (2022). https://www.rics.org/news-insights/wbef/evolution-4-0-data-for-project-cost-management.

Sawhney, A., Riley, M., & Irizarry, J. (2020). *Construction 4.0: Introduction and overview*. In Construction 4.0 (pp. 3–22). Routledge.

Turner, C. J., Oyekan, J., Stergioulas, L., & Griffin, D. (2021). *Utilizing Industry 4.0 on the Construction Site: Challenges and Opportunities*. IEEE Transactions on Industrial Informatics, 17(2), 746–756. https://doi.org/10.1109/TII.2020.3002197.

US Census Bureau (2021). https://www.census.gov/economic-indicators/.