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Review

Construction 4.0: A Systematic Review of Its Application in Developing Countries

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Abstract: This study conducts a literature review to analyse the incorporation of Industry 4.0 in the construction sector, known as Construction 4.0, in developing countries. This study utilises an effective technique, encompassing academic databases, journals, and conference proceedings, to carefully examine relevant studies published with respect to developing countries. The primary areas of emphasis involve the definition of Construction 4.0. The technologies of execution include six cutting-edge technologies such as Building Information Modelling (BIM), Internet of Things (IoT), robotics, 3D printing, UAVs, and artificial intelligence in construction procedures. This analysis also explores the awareness and understanding of Industry 4.0 in the construction sector (Construction 4.0) in developing countries before identifying where it is being applied therein. Furthermore, obstacles that impede the mainstream adoption in developing countries are identified, including but not limited to such things as insufficient technological infrastructure, skill deficiencies, and budgetary limitations. This review consolidates various studies to provide a thorough comprehension of the present condition of Construction 4.0 in developing nations. As such, this paper aims to provide a guide for future research, policy making, and industry practices in order to promote sustainable and technologically advanced construction methods in these settings.

Keywords: Industry 4.0; construction industry; Construction 4.0; developing countries; literature review; project management

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1. Introduction

The presence of humans and their activities in the industrial environment has significantly impacted the construction industry [1]. Material, energy, and control technologies are the three key areas, broken down into their respective categories, that describe the core components of the technological revolution [2]. Because of their influence on human perception, cognition, and overall experience, these domains are responsible for determining how created things perform and the power processes that drive them. By using these spheres, it is possible to create a whole new way of life.

Before the 19th century, there were restrictions on the variation of materials, which imposed engineering limits with regard to the weight, height, and strength of structures. These materials included both man-made and natural materials such as wood, stone, lime mortar, and concrete [1]. The first industrial revolution began in 1760 and lasted until around 1830. During this time, the mechanical heavy industry had a phenomenal growth spurt. As a consequence of this progression, a wide variety of new cutting-edge construction materials came into being. Glass, cast iron, and steel were some of the materials that engineers and architects developed to produce buildings that defied traditional conceptions of form, construction, and usefulness [3].

The year 1870 marked the beginning of the second industrial revolution (electricity), which was characterised by a high concentration of innovation.

These new innovations involved using practical knowledge to make technologies that could produce steel, electricity, telegraphs, and railroads quickly and at a lower cost.

The transformation in question compelled those working in the construction sector to pioneer new ideas in the fields of architectural design and the optimisation of vertical space—building taller and deeper [4].

In the middle of the 1980s, the introduction of computers and the internet led to a big change in how technology was used. This revolution included the digitalisation of mechanical and analogue processes in addition to a move away from mass manufacturing and towards mass customisation. The advent of this third industrial revolution spawned fresh interactions between architecture and technology, which proved to be a significant obstacle for the manufacturing sector [5]. Architects began using dispersed three-dimensional computer-aided design software as a representational tool to increase the accuracy of their designs and widen the extent of digitalisation.

Using computer-controlled manufacturing processes, known as CNC [6], made it possible to create complex shapes that would have otherwise been impossible to make. These techniques use a series of instructions in code to regulate the movement of a machine tool. The use of CNC technology made it easier to combine 3D-CAD models and computer-assisted manufacturing (CAM) processes [6]; subsequently, this opened the door for the mass customisation and computerisation of the production of building parts. Advanced construction techniques seemed to be less efficient and more difficult to create due to the advancement and growth of digital fabrication and digital architectural technology [6]. This set the stage for the fourth industrial revolution, Industry 4.0, which is explored in this article from a construction standpoint, referred to as Construction 4.0. Whilst there is current debate around Industry 5.0 (focused on humans and artificial intelligence working together) and Construction 5.0 (suggested to accelerate both the green and digital transitions, setting the stage for a more resilient and sustainable society and economy), this is beyond the scope of this current publication [7]. Moreover, it is beyond the current scope of inclusion in many developed, never mind developing, countries.

1.1. Research Rationale

Research in the subject area of Construction 4.0 is very much an emerging field which focuses on the fourth industrial revolution. It is becoming more well-known not just among members of the academic community but also among those working in the business world. The kinds of digital platforms that Construction 4.0 includes make it easier to share information that may be helpful/necessary to initiate certain activities [8]. This has occurred as a direct result of the revolution's impact on the building industry. Because of this, the automated collection and processing of electronic data for discrete activities within the value chain is now possible. It has become much easier to manufacture building elements, building components, and building furnishings through the incorporation of robotic technologies into the construction sector. These technologies are more frequently known as construction automation technologies. According to Woodhead et al. [9], integrating Building Information Modelling (BIM) into an information technology (IT) infrastructure makes it easier to go from a reactive strategy to an anticipatory one when controlling events [10]. Previous systematic literature reviews on Construction 4.0 have very much focused on Construction 4.0 technologies per se [11,12] or have been conducted within the context of decision making [13], BIM [14], deep learning for vision systems [15], or sustainability [16] or from the perspective of impacts on society, environment, or governance [17]. This study has the narrower focus of the application of Construction 4.0 in developing countries—an area less well researched within the literature. Therefore, this paper, which is part of a larger research project, starts to put forth a better understanding of the topic so a framework for the implementation of Construction 4.0 in developing countries can be developed. The first part of this work is to identify the status quo. This is investigated by answering a series of research questions (Section 1.2). Moving forward, this research will allow the construction industry within developing countries to create more efficient production processes and business models and enhance construction value chains [18]. Moreover, as research findings emerge, specific policy recommendations and implementation strategies tailored to the context of developing countries can be proposed.

1.2. Research Questions

The primary research question to be answered through this study is as follows: "How well adopted is Construction 4.0 in developing countries?" The answer to the research question is explored through the following six sub-questions:

- What is the universal definition for Construction 4.0 (Section 4.1)?
- What are the technologies associated with Construction 4.0 (Section 4.2)?
- What are the research gaps recently considered in Construction 4.0 in developing countries (Section 4.3)?
- What is the level of awareness and understanding of Construction 4.0 in developing countries (Section 5.1)?
- What are the applications of Construction 4.0 in developing countries (Section 5.2)?
- What are the challenges to adoption of Construction 4.0 (Section 5.3)?

2. Research Methodology

Herein, a systematic review methodology using the PRISMA approach is applied to conduct a literature review on the implementation of Construction 4.0 in developing countries. The process involves two key aspects: Firstly, the study issue is carefully defined, concentrating on developing nations and the integration of Industry 4.0 technology in construction—Construction 4.0. Secondly a thorough search strategy is created (see Section 2.1) over a relevant times period (Section 2.2) using inclusion/exclusion criteria (Section 2.3) and research databases and tools (Section 2.4).

2.1. Search Strategies (Keywords and Strings)

The chosen keywords were well-thought-out to cover important parts of the research topic. The digital transformational frameworks adopted in the industrial sector and construction sector are referred to as "Industry 4.0" and "Construction 4.0", respectively. In addition, this study was refined to focus on "developing countries" to ensure that papers dealing only with aspects related to this were included in the study area. The focus on the "construction industry" narrowed down what was researched, refining results from Industry 4.0 per se. Including "challenges" and "obstacles" allowed us to search for articles which explicitly talk about the problems faced when implementing Industry 4.0 technologies within the construction sector in developing countries.

By utilising Boolean operators (OR, AND) while also maintaining relevancy, the query sought to ensure inclusiveness. The first segment of the string, "Industry 4.0 OR Construction 4.0", was meant to broaden the search to those articles that talk about either Industry 4.0 or its application specifically within the construction field. The second segment, commonly referred to as "developing countries" or "construction industry," served as a point of orientation with respect to the literature on developing countries or the construction industry. Finally, the third segment, also referred to as "challenges" or "obstacles", narrowed the search to articles discussing the hurdles that come with implementing Industry 4.0 technologies in construction within developing countries.

2.2. Period

The period specified for the literature search is from the inception of relevant databases up to the present date; thus, this range does not have an end in a particular time frame, which enabled us to have a comprehensive look over what has been written from different angles.

The results from the period from 1994 to 2023 (see Section 3) demonstrate that the construction industry only recently started implementing Industry 4.0 and that investigations on this subject have been ongoing and on an upward trajectory. Articles that were written at the dawn of this period are quite enlightening about fundamental barriers and primary efforts made towards coordination. On the flip side, updates on the emergence of the approaches, progress, and long-term difficulties encountered by developing nations are available only from recent publications in this area (i.e., 2017 to 2023). Section 3 provides further analysis on the publications reviewed. All bibliometric data were retrieved from Scopus. The outcomes of this are explored in Section 4.

2.3. Inclusion/Exclusion Criteria

The literature review's inclusion criteria were clearly defined to ensure the importance and thoroughness of the challenges faced by developing countries in integrating Industry 4.0 technologies into their construction sector. For articles to be selected for review, they had to explicitly talk about how developing nations take up Industry 4.0 techniques when engaging in construction. This criterion was used to focus the search on the literature that directly addresses the core research question, making it easier to explore, specifically, the barriers that hinder technological advancement and innovation in these regions.

Furthermore, selected studies had to be published in peer-reviewed journals, conference proceedings, or reputable grey literature sources to fulfil the inclusion criteria. This helped to guarantee the quality and credibility of the literature that were included, as publications are put through stringent peer review processes or come from respectable conference proceedings and grey literature repositories. Prioritising scholarly and authoritative sources in reviews helps them to maintain high standards of academic integrity and reliability, which in turn improves the validity of their findings and conclusions.

In addition, all pieces of work were required to be written in English so that they could be understood and appraised more easily and hence shared more widely across and outside academic circles with regard to the research results. This criterion recognised English as the main language for writing research papers and guaranteed that no research review would be hindered by language differences as far as it considered all the people concerned.

Prioritising studies that provide depth and richness to the literature synthesized in this review made it more scholarly and practical because of the evidence-based perspectives and substantive insights contained therein.

2.4. Research Databases and Tools

The right set of tools makes it easier to review accurately and exhaustively the literature that shows problems of developing countries as far as adapting to Industry 4.0 trends in construction is concerned. Firstly, Scopus, Science Direct, and Engineering Village, amongst others, are key databases that can be checked for peer-reviewed articles, conference papers, books, and so forth.

EndNote was used to help handle search results, as such papers were stored in a way that helps with future retrieval and writing of drafts, making sure that citation is well performed. Moreover, it facilitates undertaking a systematic review by categorizing, storing, and citing all articles properly within the retrieved dataset. In addition, reference managing software increases efficiency and precision of data collection and analysis while also allowing for collaboration between investigators by centralising search results. In addition, Google Scholar and other search engines (e.g., ResearchGate) complement database searching since they allow for more sources of the grey literature and tracking of references. Because database platforms can provide advanced search functions and Boolean operators, such tools make searching more precise and results more prolific. When these research tools were used together during a literature review, challenges in executing Industry 4.0 technologies within construction sectors of developing nations were adequately and comprehensively addressed, hence increasing the robustness of findings and conclusions made therein.

3. Bibliometric Analysis

Figure 1 shows a trend of published papers in Construction 4.0 for the past 30 years. The five major countries analysed are the United States of America, China, Germany, the United Kingdom, and Japan. The USA boasts the highest directory in general, while both the USA and China have had significant increases over time. Figure 2 gives an aggregate picture on countries' published papers containing information for the top 15 nations. The USA has been most prolific here, producing 350 papers, followed by China at 250 papers and then Germany, which produced 210 papers. These two figures depict how much the USA and the People's Republic of China have dominated in terms of research on Construction 4.0 as they have registered increased activity over the last 30 years. However, slower progress was noted in the cases of Japan, Germany, and the United Kingdom, although they still closely followed the same upward trajectory.

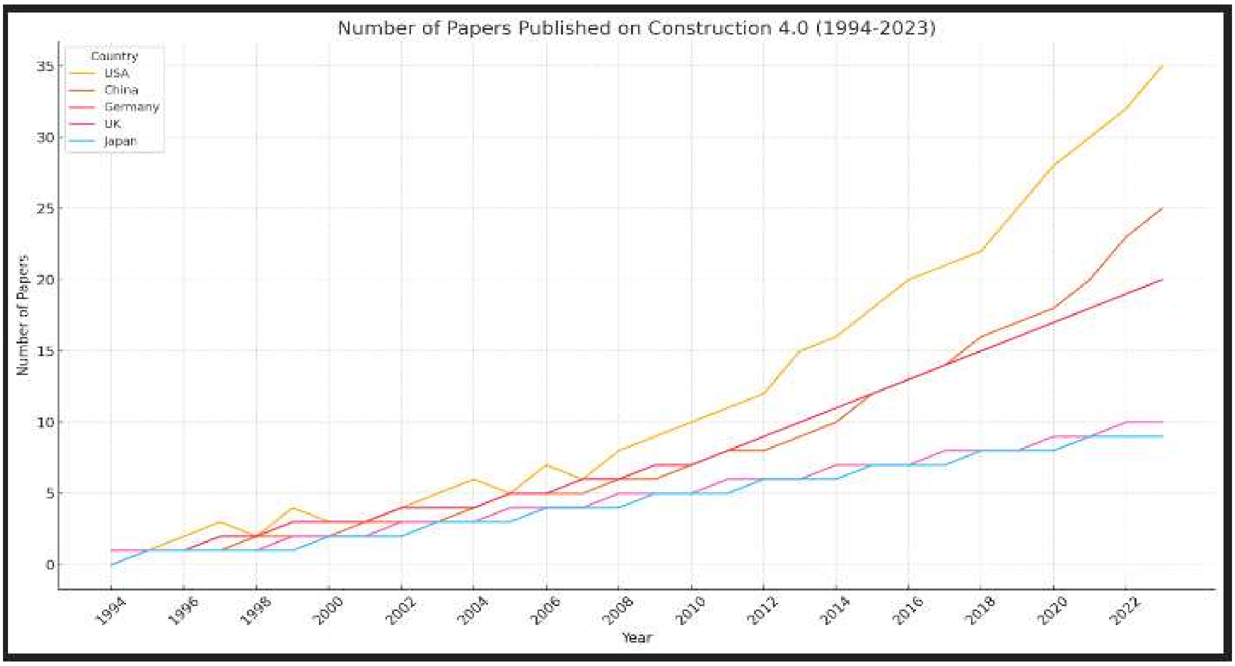

Figure 1. Number of papers published on Construction 4.0 within the last 30 years (1994–2023).

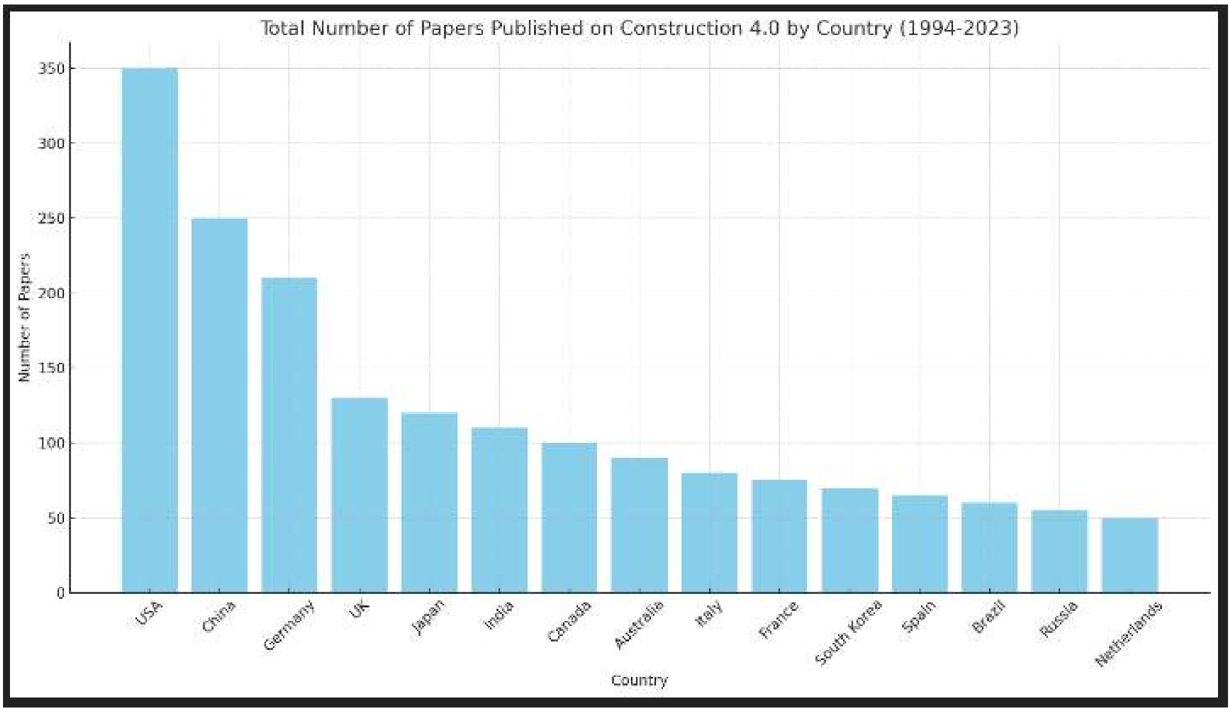

Figure 2. Number of papers published on Construction 4.0 by country within the last 30 years (1994–2023).

4. Literature Review

Conducting a systematic literature review was a sensible choice because this is an exploratory study. A systematic literature review (SLR) refers to an exhaustive and rigorous technique that is used for gathering, assessing, and bringing together earlier studies about some particular query in a research or subject matter. Systematic literature reviews (SLRs) fill gaps by providing structured and unbiased approaches that reduce research bias while ensuring transparency during the entire systematic process, which ensures accountability for research findings. The first step is to formulate a clear research question which will guide all subsequent stages of the review process. SLRs increase reliability and credibility and have several advantages compared to other types of literature reviews (e.g., narrative or scoping reviews). They inform about the subject in an inclusive manner through systematically searching for and estimating all evidence present so as not to leave important research out, and in so doing, they help to reduce bias. Moreover, reproducibility in the review process is made easier due to the organised manner of SLRs, thus making it possible for other scientists to judge whether the findings are correct. SLRs reduce bias in choice, data collection, and synthesis, hence improving the precision of their conclusions by using preset rules and procedures. Moreover, through the amalgamation of the topmost available proofs, SLRs render evidence-based decision making accessible to different stakeholders, among them researchers, practitioners, and policy makers. Ultimately, the systematic review seeks out gaps and inconsistencies in existing research, which guides future investigations and contributes to the advancement of knowledge in the field.

4.1. The Concept of Construction 4.0—Finding a Universal Definition

Ref. [19] asserts that the Construction 4.0 framework places emphasis on the conversion between physical and digital domains to improve the coordination, design, and implementation of infrastructure in the built environment with increased efficacy and efficiency. The concept of Construction 4.0 is an emerging idea that is informed by the fundamental principles of Industry 4.0, as evidenced by the prior scholarly literature. The Construction 4.0 paradigm is centred on the assimilation of patterns and innovations, akin to the notion of Industry 4.0, which encompasses the amalgamation of digital and physical technologies [19].

Presently, there exists a dearth of agreement with regard to the delineations of Construction 4.0 as posited in extant scholarly works. The preponderance of the scholarly literature pertaining to this subject indicates that it bears resemblance to, or is a derivative of, the fourth industrial revolution. The authors propose a definition for Construction 4.0, which was derived from a thorough examination of the current body of literature.

A comprehensive overview of different definitions of Construction 4.0, as documented in the literature, is provided in Table 1.

Table 1. Definitions of Construction 4.0.

Definition of Construction 4.0	Reference
"The overarching framework encompassing the digital transformation of the construction industry and the built environment is commonly referred to as Construction 4.0."	[20]
"Construction 4.0 technology is an emerging and innovative technological advancement that has been empirically demonstrated to significantly improve project performance."	[21]
"Construction 4.0 technology refers to the integration of various advanced technologies aimed at improving productivity within the construction industry".	[22]
"Construction 4.0 is fuelled by the development of various technologies, the drastic change in the needs of owners, the shift toward mass customization, and the need for green construction and sustainability".	[23]

Table 1. *Cont.*

Definition of Construction 4.0	Reference
"Construction 4.0 is seen as a subset of Industry 4.0, an application of Industry 4.0 (technologies and processes) to the construction industry, as well as a novel development in and of itself."	[24]
"Construction 4.0 is the convergence of industrial production, CPSs, and digital technologies with the ultimate goal of creating a digital construction site".	[17]
"Construction 4.0 is the combination of the "digitization of the construction industry and industrialization of construction processes"".	[14]
"Construction 4.0 is an adaptive of the construction industry for Industrial revolution 4.0 as it evolved from the manufacturing industry publicised by the German government".	[25]

By looking at these various definitions, it can be concluded that Construction 4.0 is a holistic framework that integrates multiple components, including organisational structures, operational protocols, and data systems, to optimise the planning, execution, and maintenance of assets by leveraging cyber–physical systems, the Internet of Things, and related services. The objective of Construction 4.0 is to connect the digital layer, consisting of Building Information Modelling (BIM) and the Common Data Environment (CDE), to the physical layer, consisting of the asset, construction processes, and workers/employees. According to Shawney et al. [26], a conceptual framework of Construction 4.0 should include both the physical and digital layers, as shown in Figure 3. Many of the digital tools are applicable to both Industry and Construction 4.0. Therein, it can be seen that the physical layer for a construction site has subtle differences compared to other, more industry-related processes.

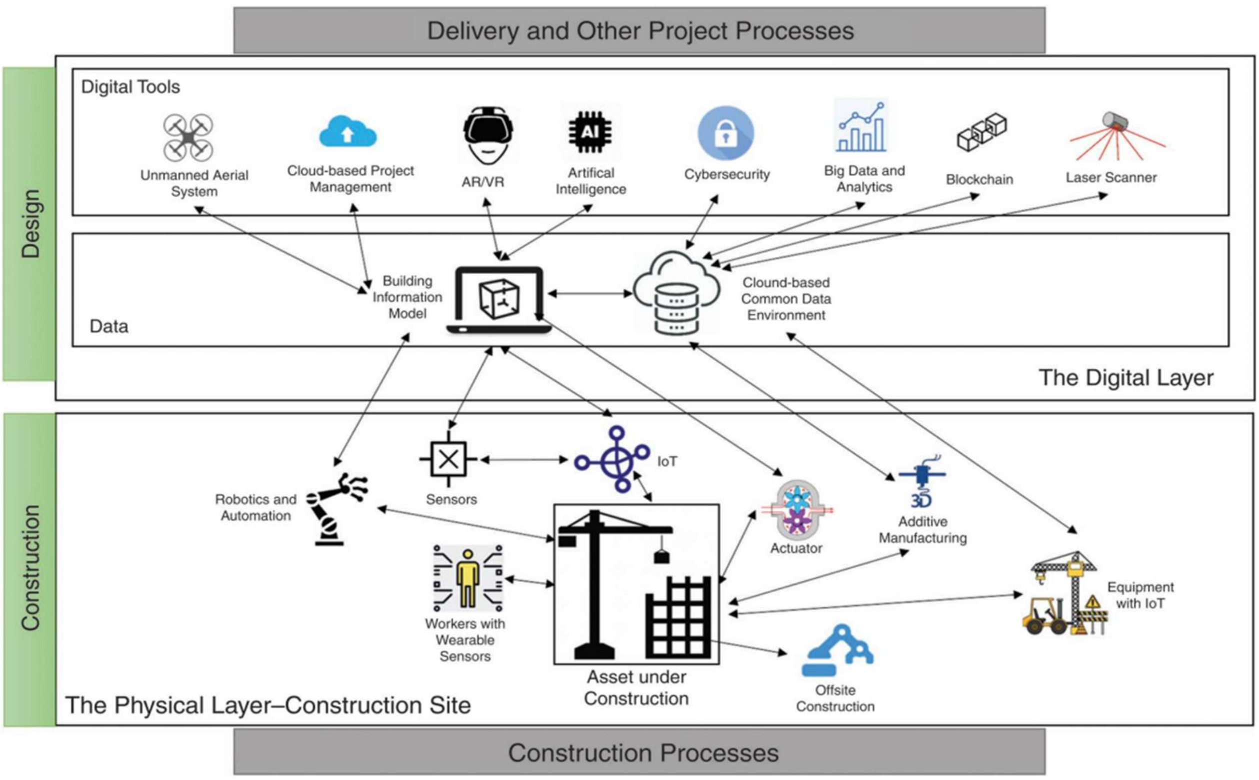

Figure 3. Construction 4.0 framework showing physical and digital layers [26].

According to [27], the primary objective of Construction 4.0 is:

"to establish a digitalized construction site that utilises various methodologies to monitor the progress of a project from inception to completion".

Ref. [27] posits that the adoption of Construction 4.0 has the potential to significantly transform not only the construction process but also the organisational and project frameworks. This, in turn, could facilitate the integration of the presently fragmented construction industry. Moreover, it has direct application to developing countries, not least Southeast Asian Nations (ASEAN).

Notwithstanding its significant profitability, the construction sector demonstrates a comparatively low degree of research and development intensity. As per the research conducted by [28], the employment growth in the ASEAN economic community (AEC) has demonstrated a downward trend over time, in contrast to other industries that have recorded a nearly twofold increase in their employment rates. Ref. [29] posits that the function of human resources within the framework of Construction 4.0 is experiencing a shift from a purely operational role as machine operators to a more strategic role as decision makers. Ref. [30] asserts that robots are employed to aid individuals in activities that are perilous, are arduous, and necessitate substantial temporal commitment.

To achieve a fruitful partnership between humans and machines, it is crucial to provide humans with adequate training. The utilisation of technological innovation, specifically robots, presents a promising opportunity for enhancing productivity within the construction industry, which is known for its labour-intensive nature. This holds particular significance for tasks that present plausible dangers and perils to human labourers. The digital construction platform utilises robots to a restricted extent, encompassing various tasks such as 3D printing, wall construction, rebar positioning, welding, and deployment of drones. Moreover, it is noteworthy that these aforementioned robots have been specifically engineered for a particular purpose, as evidenced by prior research conducted by [30]. The investigation of robots that possess multiple functions and purposes is justified given the complex environmental conditions that are encountered in construction sites.

4.2. The Various Technologies Associated with Construction 4.0

According to [31], Construction 4.0 is a paradigm shift that is marked by three transitions: the movement from industrial production to cyber–physical systems, the movement from industrial construction to cyber–physical systems, and the transfer from physical technologies to digital technologies. Cyber–physical systems encompass a broad range of technologies, including but not limited to robotics, automation, sensor technology, the Internet of Things, industrial manufacturing, on-site and off-site construction, and wearable sensors and devices utilised by personnel. Therefore, it is imperative to comprehend the technological advancements that facilitate this transition. Nonetheless, the present inquiry will concentrate on eight Construction 4.0 technologies that are frequently mentioned, as shown in Table 2.

Table 2. Technologies used in Industry 4.0 and Construction 4.0.

Technology Group	Description	Reference
Internet of Things—IoT	Through the usage of integrated sensors and wireless technologies, the Internet of Things (IoT) makes it possible to store, analyse, and disseminate data in a timelier manner. According to [1], this subject area is generally acknowledged to be an essential area of developing technology, and it has attracted substantial interest from a variety of sectors. The Internet of Things (IoT) is now used in the arena of Construction 4.0, where it is utilised to combine multiple commodities such as wireless sensor networks, middleware, cloud computing, and IoT application software. This utilisation of the IoT is currently being monitored.	[12,14,25,26,28,30–36]

Table 2. *Cont.*

Technology Group	Description	Reference
Artificial intelligence—AI	The term "artificial intelligence" (AI) is used to refer to a specific category of computer programmes that are developed with the goal of imitating human cognitive skills. The construction industry makes extensive use of artificial intelligence version 4.0, notably in adaptive vision systems that make it possible to identify a variety of components present at a building site. In addition, such a device has the capability to distinguish both voices and patterns, allowing for very accurate monitoring of the actions of construction workers. The present investigation is centred on the possibility of applying the approach to the prediction of a variety of anomalies like cost overruns, concerns of safety at a site, quality issues, etc., that could occur in the fields of building architecture, building construction, and building services. In addition, Ref. [2] found that intelligent manufacturing is a strategy that has a good chance of success.	[12,14,25,28,30–36]
Building Information Modelling—BIM	Building Information Modelling (BIM) is a software tool that, according to [37], makes it easier for all parties engaged in a building project to create, transmit, share, and disseminate information with one another. Building Information Modelling, often known as BIM, has been an essential part of the digital revolution that has taken place in the construction industry. In general, Building Information Modelling (BIM), and more specifically the integration of 5D planning and budgeting, is anticipated to result in significant cost reductions (including direct costs, efficiency gains, delay avoidance, risk mitigation, and enhanced reputation) throughout the entirety of the construction value chain, which includes design, construction, operation, and decommissioning. This includes the phases of design, construction, and operation. Ref. [38] suggests that the implementation of Building Information Modelling (BIM) has the capacity to optimise operational procedures throughout the entirety of a construction project [13]. This assertion is in accordance with the discoveries made by the previously mentioned scholars. Ref. [38] asserts that Building Information Modelling (BIM) is currently regarded as the primary technological solution for the digitalisation of the building manufacturing sector.	[2,12–14,25,26,28,30–36,39]
Three-dimensional printing	The process of producing three-dimensional objects utilising a computer-controlled apparatus is commonly known as "3D printing", which is a widely recognised term. Additive manufacturing, also known as 3D printing, is a technique that involves the creation of a tangible, three-dimensional object from a digital model using a layer-by-layer approach to add material. The ultimate outcome is the paramount aspect. Extensive research and development endeavours spanning a quarter of a century have been dedicated to exploring the applications of three-dimensional printing, as noted by [29]. It now has uses in a variety of fields, including healthcare, aircraft, and vehicles. That said, the technology that enables three-dimensional printing in the building industry exists and is well used, and it is mostly concentrated on projects of a small to medium size. The largest 3D-printed building currently exists in Dubai. These technologies have the potential to replace human labour with automated production, resulting in time savings but also loss of jobs. According to [40], the quality of the print, behaviour of the material (i.e., cement, water, aggregates, and polymers), speed, and length of time between layers are all key elements that influence the quality of the final build.	[12,14,25,26,28,30–36]
Unmanned aerial vehicles—UAVs	According to [19], the construction industry has found substantial use for drones, particularly for the purpose of observation, mapping, and monitoring during survey work, construction, and facility operations. According to Irizarry and Costa (2016), there has been a progressive growth in the use of unmanned aerial vehicles (UAVs), not least in the construction industry.	[12,14,25,26,28,30–36]

Table 2. *Cont.*

Technology Group	Description	Reference
Augmented reality—AR—and virtual reality—VR	When compared to augmented reality (AR), virtual reality (VR) represents a more developed step along the spectrum of virtuality. Virtual reality (VR) technology provides users with an immersive experience via the use of headsets that give a 360-degree field of view. This enables users to interact with a simulated world that is unique and set apart from their actual surroundings. Since 1990, there has been a major increase in the progress and application of this phenomenon, according to [32], notably in sectors such as education and training. According to [38], the use of virtual reality (VR) in training for the construction sector has the potential to reduce the risk of possible dangers, improve operational efficiency, and make it easier to identify dangerous regions. All this allows the final build to be modified prior to construction taking place.	[12,14,25,26,28,30–36,38]

Figure 4 shows ways in which various technologies can be used across the many sectors of the construction industry.

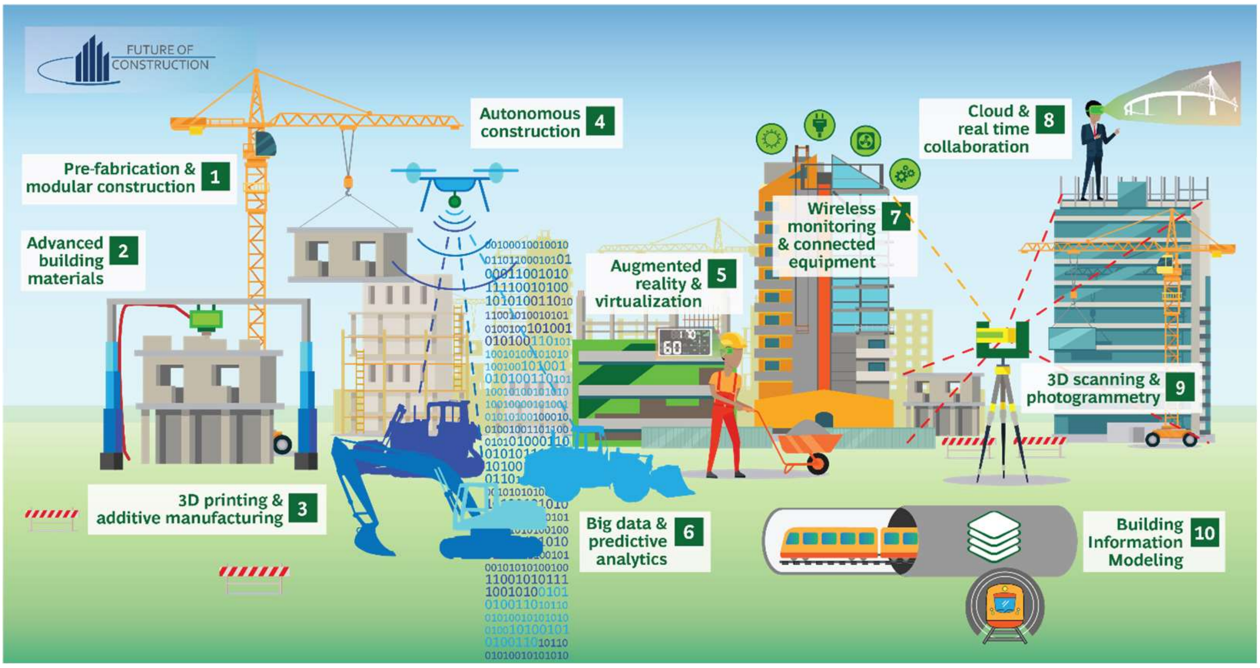

Figure 4. Technologies used in Construction 4.0. https://www.weforum.org/agenda/2018/03/how-construction-industry-can-build-its-future/ (accessed on 1 May 2024).

According to the World Economic Forum, there are six ways (i.e., scenarios) in which Construction 4.0 and all of its technologies can be embraced to build for a better future. These are important for developed and developing countries alike:

- **Building in a virtual world**. AI systems and autonomous construction replace manual construction.
- **Factories run the world**. Construction activities move to lean principles and prefabrication.
- **A green reboot.** Sustainable technologies and new materials meet tough environmental regulations.
- **Attract new talent and build up required skills**. Upskilling processes are embraced.
- **Integrate and collaborate across the construction industry's value chain**. Movement to an integrated and unfragmented value chain, which facilitates seamless data flows and integrated systems.

- **Adopt advanced technologies at scale**. Construction industry becomes quick to adopt new technologies at scale and shows less reliance on manual labour and mechanical technologies, resulting in improved productivity.

4.3. Research Gaps Considered within Recent Construction 4.0 Publications in Developing Countries

Table 3 shows research gaps considered in recent Construction 4.0 publications and the findings of that research (including methodology used and country of application).

Table 3. Research gaps considered in recent Construction 4.0 publications for developing countries.

Ref.	Date	Country	Methodology Used	Research Gap Considered	Findings of Research
[39]	2019	India	Survey, literature review	Adoption challenges (i.e., barriers and enablers) of Construction 4.0	Highlighted the need for policy support, infrastructure, and a skilled workforce.
[41]	2020	China	Mixed methods	Impact of Construction 4.0 on employment	Highlighted shifts in job roles and skill requirements alongside productivity gains from implementing Construction 4.0.
[42]	2018	Pakistan	Case studies, interviews	Infrastructure readiness for Construction 4.0	Identified gaps in technological infrastructure and skills development.
[43]	2021	Malaysia	Longitudinal studies	Skill development for Construction 4.0	Highlighted the need for continuous learning and adaptation to technological changes.
[44]	2017	Bangladesh	Action research	Integration of SMEs into Construction 4.0	Emphasised the need for collaboration and support mechanisms for mall to medium enterprises (SMEs).
[45]	2020	Indonesia	Comparative analysis	Technological capabilities in Construction 4.0	Identified variances in adoption rates and technological infrastructure.
[46]	2022	Ghana, Vietnam, and Thailand	Using a novel UNIDO database	Digital supply chain disruptions and Construction 4.0	Concluded that a firm's participation in a global value chain (GVC) is positively associated with the adoption of Construction 4.0 technologies.
[47]	2023	Malaysia	Pilot questionnaire and multicriteria business model	Adoption of Construction 4.0 by SME contractors	Identified 6 main factors (i.e., management, finance, resources, technology, personnel, and legal) that impact on SMEs adopting Construction 4.0.
[48]	2022	Nepal	Structural equation model analysis using census method	Industrial readiness for adoption of Construction 4.0	Identified that the major problem while adopting Construction 4.0 is the lack of skilled manpower in the industrial sector. In addition, customers, culture, strategy and leadership, governance, and operations have a significant effect on technology innovation decision making.
[49]	2020	Nigeria	Cross-sectional studies	Socio-economic implications of Construction 4.0	Identified opportunities for economic growth and job creation alongside challenges of inequality and digital divide.
[49]	2023	Osun State, Nigeria	Convenient sampling technique	Awareness, adoption, readiness, and challenges	Identified lack of standardisation as the biggest challenge, followed by a lack of investment and the cost of implementation.

5. Awareness, Understanding, Application, and Challenges of Construction 4.0

In recent years, the concept of Construction 4.0, also referred to as the fourth industrial revolution for construction, has emerged as a transformative force reshaping the construction industry worldwide. Construction 4.0 represents a convergence of digital technologies, physical systems, and data analytics to create smart, interconnected ecosystems within the manufacturing and construction sectors [50]. This paradigm shift promises to revolutionise traditional processes, enhance productivity, and drive innovation across various domains. Similarly, within the construction industry, the notion of Construction 4.0 has gained prominence, emphasising the adoption of digital technologies to optimise project delivery, improve efficiency, and address industry challenges [51].

A key part of embracing Industry 4.0 in the construction industry is the requirement of the construction industry to be aware of it, to understand it (Section 4.1), and then to apply it (Section 4.2)—while identifying the challenges to adoption therein (Section 4.3). As such, this section interrogates these areas within the context of developing countries, with a specific focus on India but drawing from other developing country examples.

5.1. Awareness and Understanding of Industry/Construction 4.0

Central to the successful implementation of Industry/Construction 4.0 initiatives are the awareness and understanding of key stakeholders, including industry professionals, policy makers, educators, and the general public. Awareness refers to the knowledge and recognition of Industry/Construction 4.0 concepts, while understanding entails a deeper comprehension of its implications, benefits, and challenges. Several studies have explored the levels of awareness and perceptions among stakeholders regarding Industry/Construction 4.0, shedding light on the readiness of organisations and individuals to embrace digital transformation [49,52].

Despite the growing prominence of Industry/Construction 4.0, there remains variability in awareness levels across different regions and sectors. While some organisations and individuals are at the forefront of adopting digital technologies and leveraging data-driven insights (e.g., Germany), others may lag significantly behind due to various factors, including resource constraints, lack of expertise, and resistance to change (see Section 4.3). Studies have highlighted the need for targeted interventions (e.g., education and promotional campaigns) to raise awareness and build capacity among stakeholders, particularly in developing countries but also in traditional industries [49,53].

Perceptions regarding Industry/Construction 4.0 play a crucial role in shaping attitudes and behaviours towards a digital transformation. While proponents emphasise the potential benefits, such as improved efficiency, quality, and sustainability, those who are sceptical raise concerns about job displacement, data security, and privacy risks (see Section 4.3). Understanding these diverse perspectives is essential for designing inclusive strategies that raise awareness of Construction 4.0 and address stakeholders' needs and concerns while harnessing the full potential of Industry/Construction 4.0 [54].

Based on the literature consulted, it appears that the awareness and the understanding of Construction 4.0 in developing countries have not been fully researched and therefore are areas worthy of further interrogation as part of this current research, not least to identify the variabilities that might exist given the different contextual and local conditions of a range of developing countries. Section 5.2 begins to unpack this area further.

5.2. Awareness and Understanding of Construction 4.0 in Developing Countries

There are many obstacles to knowledge that stand in the way of most construction professionals in developing countries understanding what Construction 4.0 means, let alone embracing it. First, due to restrictions in information sources and materials, lack of resources is the first roadblock to its realization. Consequently, the latest developments in Construction 4.0 could go unnoticed for the concerned parties in many industries in this region as they may lack access to internet services or suffer from low connectivity. In addition, language barriers might worsen this situation more because most of the important literature and resources are in English only, hence limiting Construction 4.0 accessibility for non-English-speaking professionals. Consequently, many people in such areas remain unaware of the possible advantages and uses of Construction 4.0 [14].

In addition, in many developing nations, there may be a lack of appropriate or nonexistent Construction 4.0-related educational and training programmes. What is more, this has made it unfeasible for construction industry professionals in the absence of formal educational as well as training interventions to have access to Construction 4.0 ideas and technologies. When construction stakeholders receive inadequate educational opportunities related to it, their understanding about how such innovations can be used for enhancing efficiency, sustainability, and productivity is affected. This means that some people who take part in different construction activities do not comprehend why they should embrace Construction 4.0 in their jobs [27].

When it comes to developing countries, awareness and comprehension of Construction 4.0 are influenced by cultural issues as well as well-entrenched traditional practices in the building field. If such innovations are believed to be breaching the prevailing norms or traditions, then some people may resist or question the embrace of such innovative means. Fear of losing a job; new systems, which are not so trustworthy; and strange working methods can be the basis of this resistance. The development of innovative technologies in construction will not be possible without changes in attitudes towards them and the successful adaptation of new technologies [28].

The solution to the problems related to knowledge and understanding of Construction 4.0 in developing countries is multidimensional. Governments, educational institutions, and industrial bodies as well as international organisations should work together on this issue to enhance the dissemination of information, create relevant educational and training programmes, and foster an innovative mindset with respect to changes in the construction industry. Developing nations can tap the full potential of this technology to propel growth that can sustain ecosystems, enhance infrastructure and elevate people's lives, provided they realize the importance of and start appreciating Construction 4.0 better [51].

5.3. Application of Construction 4.0 in Developing Countries

Within the literature, there is a lack of detailed case studies outlining where Construction 4.0 has been successfully implemented in developing countries. That said, the reader is directed to the work of Perez et al. [11] to obtain a better insight of its successful application in Brazil, the USA, and the UK. In addition, Section 4.3. also identified developing-country-specific research gaps considered within recent (i.e., 2017 to 2023) publications. What follows is a much broader discussion of the application of Construction 4.0 in developing countries.

In the context of contemporary manufacturing, specifically within the framework of Construction 4.0, it is observed that machines are interconnected in a manner that fosters collaboration, resembling a cohesive community. The process of evolution necessitates the application of sophisticated prediction tools to systematically transform data into information, enabling the elucidation of uncertainties and facilitating the making of more informed decisions within construction [55].

The advent of Construction 4.0 is anticipated to provide significant advantages to organisations that possess a comprehensive understanding of its implications for their operations. This type of change will extend beyond the operational boundaries of the company. The upcoming section examines the significance of the fourth industrial revolution on the economy of developing countries such as parts of Indian and Asian regions. It also discusses the significant measures implemented by original equipment manufacturers (OEMs), the government, and customers to embrace this emerging trend. Additionally, recent technological advancements are explored [56].

Based on the *International Yearbook of Industrial Statistics 2016*, a publication by the United Nations Industrial Development Organization (UNIDO), India's ranking has ascended by three positions, positioning it as the sixth-largest manufacturing nation among the top ten countries globally. India is not exempt from this prevailing global pattern and is progressively augmenting its portion of the global manufacturing gross domestic product (GDP). Many prominent nations are undertaking significant endeavours to stimulate manufacturing through the adoption of advancements in the fields of internet and information technology. The German government was one of the first to officially announce the implementation of "Construction 4.0," a strategic initiative aimed at advancing the country's industrial sector. Similarly, the governments of China and India have introduced their own targeted programmes, namely, "Made in China 2025" and "Make in India," respectively [57], whilst another developing country has adopted the tagline "Thailand 4.0" (https://dimerco.com/thailand-4-0-the-new-economy/ accessed on 5 February 2024).

The objective of this is primarily to promote the production of goods by both multinational and national corporations. The governments therein prioritise the implementation of enabling policies and the enhancement of infrastructure for specific key sectors, due to the presence of numerous burdensome regulations and inadequate infrastructure, not least in India.

As per the Indian Brand Equity Foundation (IBEF), the Government of India has established an ambitious objective of augmenting the proportion of manufacturing output to 25 percent of the gross domestic product (GDP) by the year 2025, in contrast to the current 16 percent. The integration of principles from Industry 4.0 with the "Make in India" initiative is imperative for the Indian manufacturing sector to achieve success in the face of global competition. India possesses a distinctive opportunity to strategically chart its own path towards smart manufacturing through innovative means. The advent of Industry 4.0 (both within and outside of construction) is anticipated to revolutionise the manufacturing sector in India and other developing countries, as it promises to enhance operational efficiencies within key industries, not least automotive, electrical, and electronics [58].

The primary emphasis will be on the progress of technology in diverse sectors. The integration of IIOT (Industrial Internet of Things), 3DP (three-dimensional printing), 3D sensors, social software, augmented reality, and location awareness is widely regarded as pivotal for the forthcoming era of intelligent manufacturing. The integration of these automation technologies is propelling the manufacturing industry towards the subsequent stage of technological progress. However, it is more frequent than not that developing countries get left behind and simply struggle to catch up, if they can catch up at all.

Construction 4.0 refers to a comprehensive framework encompassing automation, business information, and manufacturing execution systems. Its purpose is to enhance industrial operations by integrating various facets of production and commerce across organisational boundaries, thereby promoting increased efficiency [59]. Both developed countries and developing countries would benefit from Construction 4.0, although implementation in the latter is more problematic than in the former (see Section 4.3).

The Internet of Things (IoT) is regarded as a significant component of Construction 4.0, and it is anticipated that India will acquire approximately 20% of the global IoT market within the next five years. It was projected that the global market would reach a value of USD 300 billion by the year 2020 [60]. This could open up significant opportunities for developing countries in addition to developed countries; however, proactive, "bespoke" measures are required for each.

Several prominent Indian states are already undertaking proactive measures to embrace the transformative paradigm of Construction 4.0. The same cannot be said for other developing countries. The state of Andhra Pradesh, for example, has undertaken an initiative to leverage the potential of the Internet of Things (IoT) within the nation. The state government granted approval for an unprecedented Internet of Things (IoT) policy, with the objective of transforming the state into a prominent IoT centre by the year 2020 and capturing approximately 10 percent of the national market [61]. This shows the power and role of policy and governance more generally within developing countries, not least when it comes to Construction 4.0.

The Indian government implemented *"Green Energy Corridors"* with the objective of facilitating the integration of renewable energy sources. These corridors aim to develop smart grid systems capable of accommodating the intermittent nature of renewable energy inputs while also enabling the implementation of energy storage solutions. This is very much a part of Construction 4.0 for developed and developing countries alike. The importance to India can be seen in the fact that the government allocated a sum exceeding USD 1 billion towards this endeavour and has commenced initiatives in several states, including Andhra Pradesh, Rajasthan, Tamil Nadu, Gujarat, and Himachal Pradesh [62]. Given the climatic conditions in a range of developing countries, such adoption therein is technologically feasible, although it is likely not economically feasible at this moment in time.

The establishment of India's inaugural smart factory in Bengaluru marks a significant transition from automation to autonomy, wherein machines communicate with one another. Significant advancements are being achieved at the Centre for Product Design and

Manufacturing (CPDM) at the Indian Institute of Science (IISc), facilitated by a financial contribution from the Boeing Company. The future of manufacturing, often referred to as Industry 4.0, involves the integration of data exchange and the Internet of Things (IoT) in smart factories. Experts consider this development to be a revolutionary advancement. According to various reports, it is projected that the smart factory industry will reach a value of approximately USD 215 billion by the year 2025. Furthermore, it is anticipated that this industry will be embraced by all major economies [63]. Several Indian companies, like Tata Steel, Tata Elxsi, Happiest Minds Technologies, Mondelez, etc., are currently intensifying their efforts and forming partnerships with other companies to create innovative Internet of Things (IoT) and machine-to-machine (M2M) solutions. This trend is further supported by the Digital India initiative, which is spearheaded by the Government of India and is anticipated to amplify the emphasis on IoT in addressing domestic challenges, not least in construction [64].

The research [65] delves into how Construction 4.0 can be incorporated into developing nations, with a specific focus on Bangladesh. By conducting semistructured interviews with both scholars and industry insiders, it uncovers the main hurdles and opportunities associated with implementing Construction 4.0 in Bangladesh. These include challenges like inadequate infrastructure, a lack of government backing, limited expertise, the abundance of low-cost labour, and the high expense of technology installation. Despite Bangladesh's prominent role in industries like ready-made garments (RMG), it trails behind in automation and faces significant structural obstacles. The study by Jadhav et al. [65] emphasises the crucial role of government support and proactive measures from decision makers in swiftly embracing Construction 4.0, highlighting its potential to boost production efficiency, cut costs, and drive economic progress. However, it also acknowledges the necessity for substantial enhancements in infrastructure, knowledge dissemination, and policy development to fully realize the benefits of Construction 4.0.

Developed countries are in favour of embracing this new technological revolution aimed at improving human life. At the forefront of this movement is the concept of Construction 4.0, which has already been embraced and implemented by many developed nations in their industries. Meanwhile, developing countries are gearing up to adopt this concept to enhance their competitiveness in the global market. Indonesia is also involved in this; however, a lack of regional economic studies poses a significant obstacle, especially regarding Indonesia's readiness to embrace Construction 4.0. The study by [61] attempts to offer a descriptive analysis of Indonesia's preparedness for Construction 4.0, focusing on its economic and information communication and technology (ICT) development at the provincial level. Utilising data visualisation and analysis techniques such as the regional economic portfolio matrix, secondary data from credible sources were examined. Provinces like Jakarta, East Java, West Java, Central Java, Riau, Banten, South Sulawesi, and East Kalimantan emerge as the most promising, with above-average gross regional domestic product and ICT development indices. Conversely, provinces like North Sumatra have an above-average gross regional domestic product but below-average ICT development indices. On the other hand, provinces like West Sumatra, South Kalimantan, North Sulawesi, West Papua, Bali, Riau Islands, Yogyakarta, and North Kalimantan show above-average ICT development but below-average gross regional domestic product. Provinces not mentioned still have work to do to improve their economic performance and ICT development [61]. This once again highlights the importance of local context and conditions.

The Thai government has also rolled out various policies to tap into the possibilities presented by Construction 4.0. These policies fall into three main areas: digital infrastructure, skill development, and targeted industries. However, as is often the case with Thai policies, the approach to Construction 4.0 is quite broad, lacking clear prioritisation. There is a lack of effective mechanisms for evaluating these policies, leading to their implementation being largely driven by the preferences of government agencies. The current assessment framework incentivizes agencies to focus on easier tasks like training rather than tackling the foundational activities necessary to fully leverage Construction 4.0 potential. While the government shows interest in supporting e-commerce platforms and social media applications, there are concerns that stricter cybersecurity laws could hinder business opportunities arising from Construction 4.0 [66].

In recent years, there has been a surge in academic interest surrounding the fourth industrial revolution. However, there is a notable gap in research focusing on the comprehensive factors influencing the adoption of Construction 4.0 by small and medium-sized enterprises (SMEs) in developing nations, particularly in Vietnam. One study by [67] sought to fill that gap by investigating the factors influencing the actual adoption of Construction 4.0 by SMEs in Ho Chi Minh City. To achieve this, a mixed-method approach was employed, combining in-depth interviews with 12 participants and quantitative research involving 396 SME representatives surveyed online and via paper questionnaires. Analysis of the collected data was conducted using SPSS (v. 29) and SmartPLS 3 software. The findings reveal that factors such as perceived human resource development, timeliness, cost savings, product quality improvement, time savings, ease of use, business resources, business environment conditions, perceived usefulness, enhanced customer relationships, and adoption intention all positively and significantly impact the actual adoption of Construction 4.0. These results suggest that managerial efforts aimed at enhancing perceptions of these factors and highlighting the personal relevance of the technology will contribute to successful implementation. Success here is defined as the effective utilisation of Construction 4.0 technologies [68].

The advent of Construction 4.0 is anticipated to have a transformative impact on the global manufacturing sector akin to the revolutionary changes witnessed during the preceding industrial revolutions. The forthcoming revolution is anticipated to exhibit significant distinctions from its predecessors, primarily due to the presence of global supply chains and highly interactive markets. These factors contribute to a notably accelerated pace of change and the emergence of outcomes that were previously unforeseen. This observation underscores the interconnectedness and rapid dissemination of information within the manufacturing ecosystem, wherein even minor modifications in one domain can have substantial repercussions across the entire system [67]. Moreover, the advent of Construction 4.0 will facilitate the seamless transmission of information not only from manufacturers to products but also among producers, products, and, notably, customers. The capacity to adopt and leverage Construction 4.0, along with the unforeseen and swift opportunities it brings, will be crucial for achieving success in the emerging global marketplace. Moreover, it would be good to see these outcomes shared equitably between a range of developing countries where a vision for Construction 4.0 is not yet fully (and sometimes partially) considered, let alone fully established. The successful progression of innovation from a conceptual stage to the mass production of a product is crucial for achieving desired outcomes. Additionally, it is equally imperative to establish a skilled manufacturing workforce capable of swiftly advancing these innovations [57–68]. For developing countries, this is not always straightforward but is instead prone to many challenges along the way (see Section 5.4).

India has implemented various initiatives aimed at fostering innovation and establishing a skilled workforce for the manufacturing sector. Certain entities have achieved a significant level of establishment, while others are relatively recent and characterised by their innovative nature. The advent of Construction 4.0 has brought forth significant prospects, underscoring the imperative for a skilled and adaptable workforce and production capability that are capable of addressing both current and future demands [69]. This is reflective of the requirements for developing countries, and the value of upskilling in these countries cannot be underestimated. Moreover, the assessment of Construction 4.0 readiness among industrial enterprises in developing countries is imperative due to the significant challenges currently confronting the manufacturing sector. The challenges discussed pertain to disruptive concepts such as the Internet of Things (IoT), cyber–physical systems, and cloud-based manufacturing. As a result, the growing intricacy across various levels within firms gives rise to ambiguity regarding their awareness to and understanding of Industry 4.0, let alone Construction 4.0, although both are intimately connected (Section 4.2). Notwithstanding this, in both developed and developing countries, the corresponding organisational and technological capacities, as well as the appropriate strategies to enhance them, are required. This highlights the need for preparedness. As such, the German Engineering Federation (VDMA), supported by experts and industry representatives, devised a comprehensive six-dimensional model for evaluating the preparedness of enterprises for both Industry 4.0 and Construction 4.0 alike [70], as shown in Table 4. The 2023 Network Readiness Index is also a useful gauge in this respect, as shown in Figure 5.

Table 4. Industry 4.0—six-dimensional model of Industry 4.0 [70].

Operational Excellence Enhance efficiency through greater automation. Product customisation at the cost of mass-produced products.	**Enhanced Services** Higher revenues from digitally refined products. Access to new markets.
Physical Elements	**Virtual Elements**
Smart Factory Digital modelling. Equipment infrastructure. Data usage. IT systems.	**Strategy and Organisation** Strategy. Investments. Innovation management.
Smart Product ICT add-on functionalities. Data analytics in usage phase.	**Smart Operations** Cloud usage. IT security. Autonomous processes. Information sharing.
Employees Skill acquisition. Employee skill sets.	**Data-Driven Services** Services. Shares of revenue. Shares of data used.

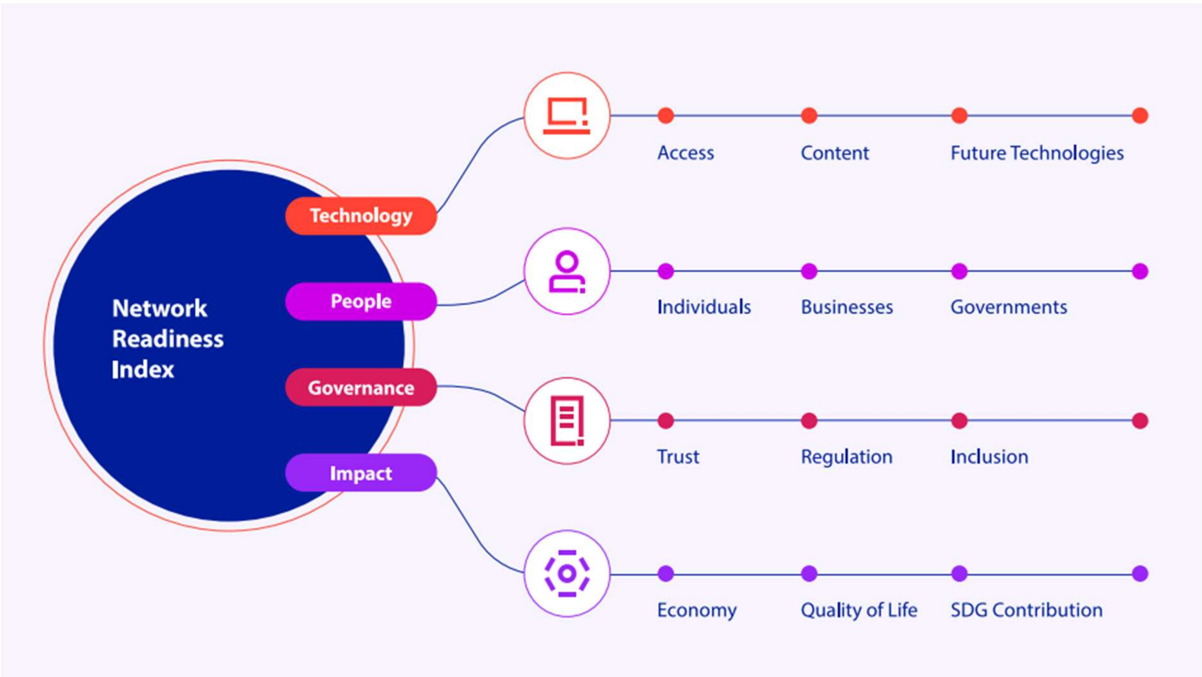

Figure 5. Network Readiness Index (NRI) 2023 model—https://networkreadinessindex.org/ (Accessed on 1 January 2024).

Hizam-Hanafiah et al. [71], after a review of the literature, suggested six dimensions that should be used to ascertain Industry 4.0 readiness, including technology, people, strategy, leadership, process, and innovation—not dissimilar to those found in the NRI. In 2023, according to the Network Readiness Index (NRI—https://networkreadinessindex.org/ Accessed on 1 January 2024), India attained a position of 60 out of 134, just below the value of 61 achieved in 2013 but above the value of 91 achieved in 2016. Low- and lower-middle-income countries dominate the lower places with developing countries such as Nepal (113), Nigeria (109), Pakistan (110), and Bangladesh (112); those with middle incomes dominate the middle-third places and include Thailand (67), Sri Lanka (63), Vietnam (62), and Malaysia (40). In contrast, those with higher incomes or upper-middle incomes dominate the top 50 places, with the USA taking the top spot, closely followed by Singapore. The best performing low-income country is Rwanda (100).

As such, there is a fear that developing countries could and likely will be left behind unless a vision with underpinning objectives and allied actions, such as those adopted by India, are adopted. Here are some examples:

- As per the Indian Brand Equity Foundation (IBEF), the Government of India has established an ambitious objective of augmenting the proportion of manufacturing output to 25 percent of the gross domestic product (GDP) by the year 2025, in contrast to the current level of 16 percent [55].
- The Internet of Things (IoT) is anticipated to acquire approximately 20 percent of the global IoT market within the next five years, making it a significant component of Industry 4.0 in India. Based on the forecast provided by the India Brand Equity Foundation (IBEF), it was anticipated that the Internet of Things (IoT) market in India would experience a compound annual growth rate (CAGR) exceeding 28 percent within the period of 2015 to 2020. By 2025, it is suggested that IoT devices will exceed 2 billion in India.

The Indian government has implemented various initiatives, including the establishment of green corridors and the promotion of the "Make in India" campaign. In addition, developing countries need to score better across all four pillars of technology, governance, people, and impact to better integrate with the Construction 4.0 agenda. However, numerous challenges still exist [72], and these are presented and discussed further in Section 4.3.

5.4. Challenges to Implementing Construction 4.0

Utilising contemporary Construction 4.0 technology in developing countries poses several challenges that affect all elements of the construction sector (Table 5). A more detailed narrative follows.

Table 5. Challenges to Construction 4.0 in the construction sector in developing countries.

Challenges	Challenges	Ways to Overcome Challenges
Limited infrastructure and connectivity [42,49]	Sufficient infrastructure and connection are essential for the effective implementation of Construction 4.0 technology; however, in developing countries, these are not always available or reliable.	Access to dependable internet access, mobile networks, and digital infrastructure is essential for immediate communication, data sharing, and remote monitoring of construction projects, especially in distant or underserved regions.
The complexity of IoT solutions [44,49]	Fully integrating emerging technologies like Building Information Modelling (BIM), Internet of Things (IoT), drones, and augmented reality into current building procedures may be difficult.	It is essential to provide smooth interoperability and compatibility across various systems and software platforms to fully use the advantages of Construction 4.0.

Table 5. *Cont.*

Challenges	Challenges	Ways to Overcome Challenges
Skill gap in IoT development [39,41,42,48,49]	Implementing Construction 4.0 technologies need a proficient staff capable of utilising and overseeing sophisticated digital tools and equipment.	Offering sufficient training and upskilling programmes for construction experts and workers is crucial to close the skills gap and guarantee the effective use of contemporary building methods.
Data production, protection, and management [49,53]	Construction 4.0 produces extensive data from sensors, drones, and BIM models, requiring effective data management and security measures. Construction organisations have substantial hurdles in managing, analysing, and safeguarding these data.	Securing data privacy, integrity, and cybersecurity is crucial to protect sensitive information and maintain trust with stakeholders, not least in developing countries.
Cost and return on investment (ROI) [49,61]	Construction 4.0 technologies provide several advantages including enhanced efficiency, productivity, and quality, but the initial expenditure is likely to be substantial.	To obtain a positive ROI, one must perform a thorough cost–benefit analysis, engage in long-term planning, and implement efficient project management to support the integration of contemporary technologies and guarantee financial gain.
Regulation and standardisation [47,49,61]	The regulations and laws concerning the use of new technology in building are always developing. Businesses implementing Construction 4.0 principles may have difficulty in complying with regulations, standards, and safety, quality, and liability concerns.	It is crucial to address legal and regulatory obstacles to reduce risks and guarantee adherence to industry norms. Therein, standardisation will help broker greater uptake of Construction 4.0.
Culture change [73] and resistance to change [49]	Developing countries may be resistant to a change in the way things have always been done. As such, implementing Construction 4.0 would require a substantial culture change in the construction industry towards a more collaborative, data-driven, and digitally enabled project delivery strategy.	Overcoming reluctance to change, cultivating an innovative culture, and encouraging cooperation among stakeholders are crucial for the effective implementation and approval of contemporary building methods. Education is key in identifying the short- and long-term benefits of Construction 4.0.

Organisational readiness is another key determinant of successful Industry/Construction 4.0 adoption. Organisations must have the necessary infrastructure, capabilities, and leadership support to effectively implement digital technologies and drive organisational change. Factors influencing readiness include technological infrastructure, financial resources, human capital, and organisational culture [73]. Studies have underscored the importance of leadership commitment, strategic vision, and employee engagement in fostering a culture of innovation and continuous improvement [71].

The implications of Construction 4.0 extend beyond technological advancements to workforce development and skills requirements. As automation and digitalisation reshape job roles and tasks, there is a growing need for upskilling and reskilling the workforce to remain competitive in the digital age. However, bridging the skills gap poses significant challenges, requiring coordinated efforts from governments, educational institutions, and industry stakeholders. Strategies such as lifelong learning, competency-based training, and apprenticeship programmes are essential for equipping the workforce with the skills needed for Industry/Construction 4.0 [74].

The development of Construction 4.0 effects every aspect of a firm, which has resulted in companies being stricter. Businesses that were the first to enter a market are, without a doubt, privileged and today hold a dominant position in their respective sectors. According to [75], even when Construction 4.0 is already a reality, there are still challenges that need to be taken into consideration while it is being developed. To be able to communicate between robots and people, Construction 4.0 must make use of artificially intelligent solutions. An in-depth analysis showed that artificial intelligence would both remove work and provide new work opportunities, particularly in domains where the powers of artificial intelligence do not equal the skills of humans [76]. The adoption of artificial intelligence solutions will be mandatory for industries; those that do not do so risk falling behind their rivals. A collection of tools that accurately accept inputs and process them into an output in a way that is at least as good as what a person would have achieved is called machine learning, which is another term for artificial intelligence. Artificial intelligence is unquestionably a result of these types of processes.

Ref. [77] concluded that for policy makers to successfully adopt Construction 4.0, they need to pay equal regard to the problems which, as previously stated, include technical, organisational, governmental, and fiscal issues. CPSs, Internet of Things devices, data storage, machine-to-machine communication, cloud computing, and other similar technologies all need high-speed, continuous broadband internet connectivity to operate in real time via integrated internet networks, which necessitates the existence of an efficient internet network [66]. Due to the real-time sharing of massive amounts of sensitive company data and information interchange throughout the whole supply chain network, there are concerns about an increased, low-latency, accessible bandwidth of the internet as well as about cybersecurity [28]. The absence of standards and benchmarks in developing countries is yet another challenge that technical experts and managers face in the context of digitalising company processes. A set of guidelines that are constructed for dynamic optimisation models is required to facilitate the smooth transfer of data between various stakeholder groups across the entire value chain [71]. These stakeholder groups include government regulators, manufacturing systems, machines, logistics providers, and consumers.

Through the strategic management of technology, productivity, and automation in every business activity, Construction 4.0 strives to further the objective of promoting corporate sustainability [16], never more important for developing countries that typically do not score highly when it comes to global SDGs. The process of doing business gets more challenging as the level of customisation within it rises. As a result, it seems that it is unavoidable that all phases of a product's life cycle will be considered, let alone be significantly digitalised, which will result in ongoing uncertainty. Ref. [78] is a study that looked at risk-related uncertainty and stated that the origins of this uncertainty are highly important. Operational risks are accidents that have the potential to occur while a firm is carrying out activities both internally and externally. These are likely to be higher in developing countries where there is a clear connection between these occurrences and the production environment, human capital, machinery, and equipment environment, as well as other components of Construction 4.0 [58]. These can be lacking or of poorer quality in developing countries. Moreover, it was said by [32] that the risk that is associated with the technology of Construction 4.0 includes but is not limited to the legal and political climate, the environment, and the economy, which vary significantly from developing country to developing country. All have a stronger influence on the risk structure, which necessitates study to provide an appropriate response for Construction 4.0. According to [69], the inefficient legal framework for Construction 4.0 and the already weak standards for Industry 4.0 have both contributed to an increase in the legal risks, which has made the adoption of Construction 4.0 difficult for industrial firms, let alone those located in developing countries. Technological advancements connected to Construction 4.0 have the potential to monitor and regulate factors that contribute to pollution, hence reducing environmental concerns and removing the need for direct human engagement. According to [29], it is concluded that to make the most of the benefits that Construction 4.0 has to offer, it is necessary for industrial enterprise researchers and practitioners to carry out an analysis of the relevance of the anticipated dangers and pitfalls.

6. Research Gaps to Be Filled

The lack of research in the field of Construction 4.0 in countries such as India, Bangladesh, Indonesia, Thailand, and Vietnam poses problems and possibilities for the digitalisation of the construction sector. Although there has been notable advancement in comprehending and using Construction 4.0 principles in industrial sectors, the building industry is falling behind in fully utilising digital technology. A significant research gap exists in the insufficient comprehension (awareness and understanding) of how Construction 4.0 concepts and technology may be efficiently implemented in developing nations such as

Nepal, India, Bangladesh, and Indonesia, where building activities have a vital impact on economic growth.

Furthermore, there is a dearth of thorough research investigating the preparedness of the construction industry in these nations to adopt Construction 4.0 projects. The implementation of digital technologies in construction processes is significantly hindered by infrastructural restrictions, such as insufficient technology infrastructure, low levels of digital literacy, and a lack of worker skills. Moreover, the fragmented structure of the construction sector, which heavily depends on small and medium-sized firms (SMEs) and subcontractors, adds extra complexity to the adoption of Construction 4.0 solutions.

Another area of study that must be addressed is the socio-economic impact of Construction 4.0 in these nations. Although the potential advantages of adopting Construction 4.0, such as enhanced productivity, efficiency, and sustainability, are increasingly acknowledged, there is a lack of empirical research about how this adoption affects job creation, labour practices, and income inequality in the construction industry. Comprehending the socio-economic consequences of Construction 4.0 is crucial for policy makers and industry stakeholders to develop comprehensive plans that foster both economic expansion and social fairness.

In addition, there is a lack of research that specifically examines the legislative frameworks and regulatory settings that support the implementation of Construction 4.0 in these nations. Robust laws and regulations are essential for establishing a conducive atmosphere that fosters innovation, investment, and cooperation among all parties involved. Nevertheless, current rules may be deficient in terms of precision or in their capacity to tackle obstacles encountered by the construction sector, such as the establishment of common standards for the exchange of information, safeguarding data privacy, and protecting intellectual property rights pertaining to digital resources.

7. Conclusions

The findings suggest that there is a discernible, evolving, and continuous dialogue surrounding Construction 4.0 in developing countries. The current analysis underscores the inadequacy of a thorough understanding concerning the ramifications of Industry 4.0 on the construction industry owing to the scarcity of primary research articles available. The authors identified that numerous definitions for Construction 4.0 exist, and these tend to be changed to fit the user requirements. Six main technologies and the roles they play in Construction 4.0 were emphasised, not least the role of BIM in facilitating collaboration between cyber and physical systems. This has led to the development of a comprehensive cyber–planning–physical ecosystem that seamlessly incorporates BIM features throughout all phases of construction project life cycles. Furthermore, there exists a scarcity of scholarly inquiry concerning the awareness, understanding, and application of Construction 4.0 in developing countries. Moreover, there appears to be a lack of enquiry on the barriers that currently exist towards its adoption and ways to overcome these in developing countries. Conducting research in this domain is crucial for transforming the construction sector and its financial landscape while also integrating Construction 4.0 technology and practices. Construction 4.0 can bring about a favourable metamorphosis in developing countries, not least by enhancing the construction life cycle in terms of both quality and performance.

Bringing Industry 4.0 to the field of construction in emerging economies, also known as Construction 4.0, has vast potential for changing the way traditional construction is implemented and for better integration to embrace sustainability. Although developing nations have various obstacles such as insufficient technological accessibility and poor infrastructure, among others, they have much to gain from implementing Industry 4.0 in their buildings. Through the application of modern technologies such as Building Information Modelling (BIM), Internet of Things (IoT), robotics, and artificial intelligence, emerging countries can optimise project performance, cut costs, and boost overall efficiency. In addition, embracing the principles of Construction 4.0 initiates creativity, encourages ecological consciousness, and enhances infrastructure quality in such areas. Achieving

Construction 4.0's full transformative potential needs joint policies, training, and global partnerships to tackle the outlined challenges. Developing countries can lead the way to a more resilient, productive, and technologically advanced construction sector by putting their money into education in technology, creating a culture of innovation, and putting in place regulatory frameworks in construction, thus ensuring that economic growth is sustainable and beneficial to the people [16].

8. Limitations of the Study

Within this study, whilst the literature search used numerous appropriate academic search engines, the authors are aware that there is always a possibility of academic bias when searching these alone and limiting the searches to journals and conference proceedings on issues of Industry 4.0 in the construction sector of emerging nations. In other words, valuable inputs from industry reports and the grey literature may have been overlooked. Moreover, this review's scope might have failed to capture pertinent studies written in foreign languages unfamiliar to the investigators, which would have otherwise ensured comprehensiveness in results. Additionally, this research examines topic areas of Construction 4.0's definition and its execution technology, level of awareness, and applications, meaning that issues like cultural barriers or legalisation challenges might not be covered. Additionally, pinpointing what holds back widespread use in developing countries and identifying local contextual difficulties faced by these regions and possible policy formations to help overcome them may not yet be fully clear. These are all aspects for future research within this area.

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