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Assessing Construction Transformation and Implication on Future Production Flow System

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ABSTRACT

Construction has witnessed great transformation since its cradle. The material, product and production subsystems have changed. Plant and heavy equipment have been introduction in the procurement process. The changes have disrupted production flow system at different milestone in its developmental history. The most recent development called Construction 4.0 is a digitalized era where interconnectivity of things is transforming the construction system with promising disruptions once again if fully actualised. Unlike the prevailing Construction 3.0 that relies more on hard technology, the unique feature of Construction 4.0 era blends both hard and soft technologies equally in its operation. This enables automation of machines and their interconnectivity to communicate and perform tasks. These technologies are at different levels of development and tests. Researchers seem to have paid less attention in assessing their implication on the future construction workflow. Understanding this is prerequisite to proper planning for early adoption into construction systems flow for early and maximum benefits. This work appraised 21 relevant technologies that are at the frontiers of construction 4.0. While some of these technologies might not have been initiated from the construction domain nor being construction specific, their application in the construction sector have been clearly availed. The technologies were subsequently classified along their relevance in construction procurement stages. This provides information for easy identification and choice of construction 4.0 technologies to meeting construction solutions. This also enriches literature on the subject. Professionals and investors should get prepared and be guided on informed decisions in achieving Construction 4.0.

Key words: construction 4.0, digital technology, innovation, production flow system, industrial revolution

INTRODUCTION

The advent of information and communication technology (ICT) has not only disrupted the general perception of the way of doing things and the way human beings think and communicate, but the learning process and work-flow systems have equally been upset (Apriliyanti and Ilham, 2022). Like all other industries, construction has been affected by ICT. Being engaged in the production of buildings and engineering products such as houses, schools, roads, dams and factories, the sector have been affected. The industry's production flow has witnessed disruptions from its cradle to date with significant improvements in quality, complexity, productivity and delivery time, courtesy technological advancements. Three distinct Industrial revolutions (IR1.0, 2.0 and 3.0) that affected the construction flow system is undisputable in literature. These revolutions relate to eras of advancements in technologies achieved. The revolution eras brought about significant economic uplift and improved the quality of lives of human beings. A new phase of revolution, industrial revolution 4.0 (IR4.0) is emerging under a digitalized sector. Under IR 4.0, the term construction 4.0 referring to the fourth construction revolution has been defined (Shafei, Radzi, Algahtany and Rahman, 2022). Yet, scholars are still diverse in opinion on whether IR4.0 has actually started or not (Woodhead, Stephenson, and Morrey, 2018). Notwithstanding, the indices pointing to IR4.0 which is an intelligent network of people, machines, and industrial processes has been described (Yama, 2018). By the time IR 4.0 gets matured, construction production flow will be disrupted once again, possibly, beyond expectations, which might include

(Shafei et al. 2022) a complete change in the physical assets' design, development, and preservation. An emerging technology, quantum computing, is poised to solidify the fourth revolution in the industry by significantly enhancing computational capabilities, enabling more complex simulations, optimizations, and data analyses capabilities (Kanamori and Yoo, 2020). It is predicted to either amplify the effects of IR4.0 or pave the way for a new industrial revolution, potentially IR5.0 (Apriliyanti and Ilham, 2022), that will be characterized by quantum-enhanced decision-making systems and automation. **However, there seems to be insufficient assessment of the effect of these technologies on construction, especially on how the future of construction production flow will fare under full IR 4.0 (**Shafei, Radzi, Algahtany and Rahman, 2022). It is pertinent to state that the third world, especially the African continent has often lag in the adoption/adaption of technological innovations in process improvements (Ugochukwu, Akabgu, and Okolie, 2015) when compared to the West and many Asian countries. For example, the adoption of Building Information Modelling (BIM) in construction innovation, a key construction 4.0 drive, is advanced in countries like the US, UK and Germany (Kalfa, 2018). This contrasts the African countries like Nigeria where the application is still poor (Ugochukwu, Akabogu, and Okolie, 2015; Onungwa, Uduma-Olugu and Igwe, 2017) despite over 40 years of BIM's developmental trend (Latiffi, Brahim and Fathi, 2014). Delayed adoption of technological innovations causes delayed benefits and subsequent delayed economic growth (Onungwa et al. 2017). Onungwa et al. (2017) ranked the **"lack of awareness" of technology innovations first among seven factors impeding the adoption of innovations in construction. Assessing the technologies creates awareness. T**he prediction of future construction workflow will be possible so as to alert stakeholders on the need to reposition themselves and get prepared for the construction 4.0 innovations. This work therefore is set to create awareness on construction technological innovations while predicting their impact on the procurement process. Policy makers, practitioners and investors will see the need to providing relevant infrastructure for a quick and proper adoption of these innovations for service delivery. To achieve the aim, the objectives of the work are to:

1. Discuss the key construction transformation beginning from its cradle to date
2. appraise the technologies driving construction 4.0 and their impact on the construction procurement
3. predict future construction workflow system under construction 4.0.

LITERATURE

Industrial revolutions

Innovations are changes that transform a system or product. When the changes are dramatic and dynamic they are referred to as revolutions. Revolutions occur in all aspects of life including political, economic, industrial, technological and socio-cultural aspects. Industrial revolutions (IR) have occurred in human history and still on-going, bringing significant changes in construction systems and driving the sector along accelerated growth (Mohajan, 2019).

The history of industrial revolutions began in England which witnessed technological advancements that transformed the economy of the nations affected. The first revolution (IR1.0) witnessed key inventions like fire furnace, Portland cement, steel and the steam engine. These items formed a bedrock for the advent of IR2.0 christened the "technology revolution". Plant and heavy construction equipment like earth moving, concreting, haulage and drilling were introduced into production. Wireless communication technology and electric energy also came up, computers began to take shape (Keats, 2012) which also formed key components of the third industrial revolution. The third industrial revolution (IR3.0) saw information and communication technology (ICT) becoming key in businesses outfits. Because of the advancement of telecommunication and energy engineering, the society was described as the "information and knowledge society". The IR3.0 was a "Big Bang Disruptions" to the status quo. Previous technologies were considered marginal, low quality and only partially innovative. IR3.0 driven by software, memory, and communications technology rather became mainstream, high quality, very innovative, and lower in cost.

There's still a diversion in opinion on whether IR3.0 lingers or IR4.0 has taken over. Arguments against are that there hasn't been any significant economic impact in the society and the global economy is yet to experience a paradigm shift to justify a new era away from IR3.0. Previous revolutions changed human lifestyle in terms of earnings and living standards with great impact on global economy which is yet to reoccur. On the other side, proponents rely on the velocity, scope, and systems impact to attest to IR4.0 which began in the early 21st century (Schwab, 2016; Apriliyanti and Ilham, 2022). It is believed to characterized by the integration of different scientific knowledge domain like physical, digital and biological, for scientific advantage. Key scientific fields of the technological innovations include:

- data-driven technologies
- automation
- robotics,
- nanotechnology
- advanced artificial intelligence techniques
- programming.

Furthermore, the widespread use of the internet has led to the interconnection of devices, systems, subsystems and services. The IR4.0 is witnessing inter-connectivity between physical, digital and biological entities that are communicating and executing tasks. In IR4.0, location is not a barrier to communication and connections. Located at different places far or near, machines and biological entities can be interconnected into a network to communicate or exchange data and execute tasks.

Construction transformation with key innovations

The Industrial Revolutions that occurred and impacted the varying sectors of the economy of nations came along with varied innovations which also transformed the construction industry. Construction product complexity, materials, management system and the production tools changed over time. The changes from crude to simple tools and later, heavy plant and equipment, blended with material advancement transformed the product characteristics, the production style and its management. More difficult jobs, mass movement and lifting of heavy materials become possible. The trend in construction industry transformation and key characteristics from its cradle till date have been discussed (Yaman, 2018; Karimov, Sarybaev, Kaipnazarov, Djumageldiev, Reymbae, and Kholdarova, 2024). This can be viewed in six stages as summarized in Figure 1.

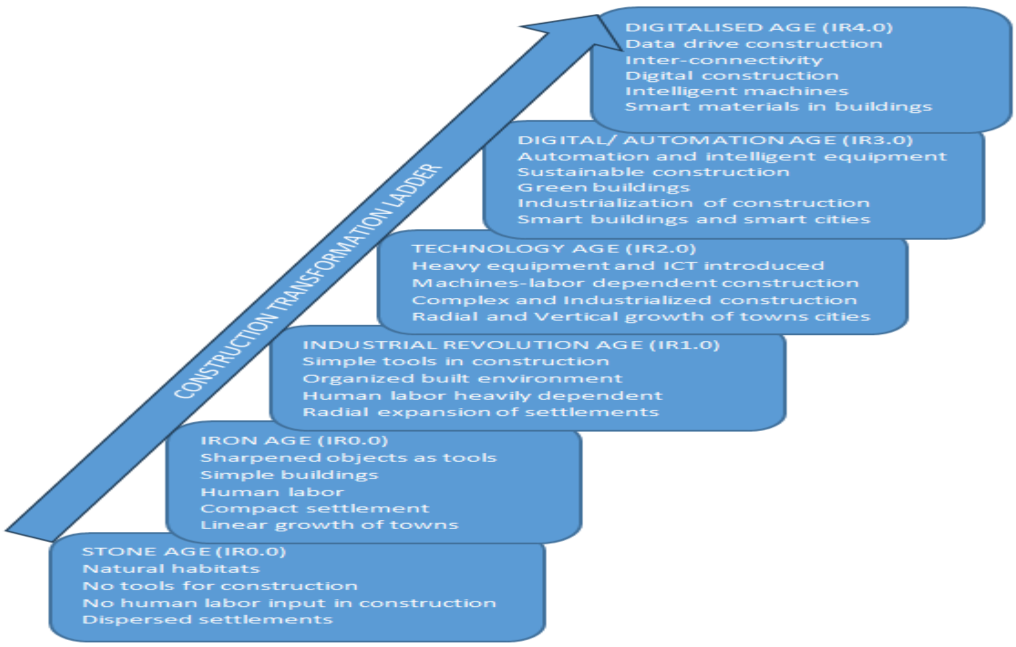

Figure 1: Construction transformation ladder and key characteristics

- **Stone age**: this is a pre-industrial revolution age, a stage the early man lived in natural caves and thickets as shelter. At this stage, man virtually makes very little or no input on his habitat. Early humans depended on their physical surroundings and lived as nomads without any fixed residence (Karimov, Sarybaev, Kaipnazarov, Djumageldiev, Reymbae, and Kholdarova, 2024). The kind of tools used when the need arose were mere natural objects obtained around him. Communities were dispersed. Construction at this level was at its lowest as man was not able to significantly alter his environment (Karimov, et al. 2024).

- **Iron age**: a pre industrial revolution but bronze and iron were discovered. The iron was used to improve natural objects to serve as improved tools. Woods were carved and stones sharpened by the iron which enhanced their value and used in construction. At this stage, man's input in shaping his dwellings improved. He began to build his habitat and raised simple huts and makeshift structures as modernized dwellings (Vetan, 2017). Linear expansion of settlements began. The main change here is man's ability to create a facility as his dwelling even though in a crude way.

- **Industrial Revolution age (IR1**.0). there was a breakage from crude ways of doing things as man invented and began to rely on machines. Societies became agrarian as people moved from villages to towns concentration for jobs. The need for infrastructure to accommodate new commers became pressing. Cement was invented at this level and simple hand-held tools used to improve further the art of construction. Construction then depended heavily on human labor. Towns and cities came up and expanded radially.

- **Technology age (IR2.0)**: plant and heavy equipment were invented, like the earth moving, hauling, hoisting, compacting, drilling, surveying and concreting equipment. The concept of sustainable construction was born and material science became advanced. Various construction materials that perform wonderfully and sustainably were introduced into construction technology. The technologies enabled the application of modular and prefabricated construction. The manual labor was heavily transferred on machines which handled most of the difficult tasks. Towns and cities grew vertically as more complex high-rise buildings became possible, in addition to horizontal growth. However, humans themselves handle the tools and sit on the construction equipment to operate them.

- **Digital and Automation age (IR3.0)**: this stage witnessed the introduction of information and communication technology (ICT). Computers became commonly used in business enterprises and internet invented. As the trend of development continued, the era witnesses the use of artificial intelligence, robots and drones in construction activities. Some machines are automated and may not need humans (ROBOTS) or need only minimum human input (COBOT) in task accomplishment.

- **Digitalise age (IR4**.0): digitalised construction is the use of internet to connect everything related to construction procurement. Using the Internet of Things (IoT), physical objects, biological and non-biological, are interconnected to communicate. Generally, both humans, objects and machines are interconnected to communicate with each other and share data for task performance. A special note is that machines are made to copycat human brain, perceive their environment, acquire data, analyse the data and take decisions to act based on the results with less or without human assistance (Bock and Ikeda, 2014). If interconnected, performance will be superb.

METHODOLOGY

This work is a review of existing technologies relevant to construction 4.0. It identifies the technologies that are driving construction innovation 4.0 through wide literature search. Each technology identified and found applicable to construction 4.0 delivery was discussed. The technologies were subsequently classified based on their common functions and application in the construction production flow system. The steps are summarized in figure 2.

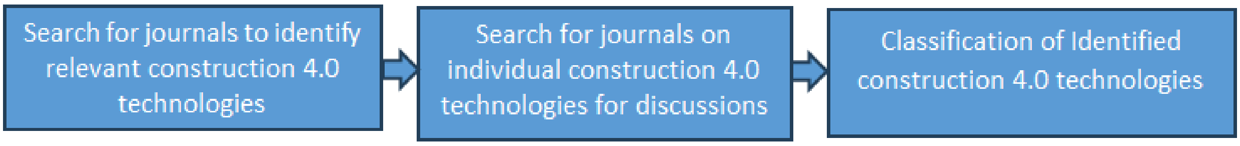

Figure 2: Methodology

Step one was to search for journals from the net with the sole purpose of identifying relevant technologies on the subject using key words like, construction 4.0, innovative technology and construction innovations. The search was conducted on free data banks including Google scholar, academia and ResearchGates. One hundred and twenty-four journals came up and the researchers screened the titles of the articles. Seventeen journals were found relevant and reviewed. Twenty-one technologies driving construction 4.0 were identified. The second step was that each of the technologies were further searched using the name as key word so as to get articles that discussed their features and application in construction innovations. These were reviewed for the proper understanding of each technology. The third stage was to group the technologies according to their functions in the construction process flow.

Identifying Technologies that drive construction 4.0

Several technologies driving construction 4.0 are already operational (Statsenko, Samaraweera, Bakhshi and Chileshe, 2022). These technologies as in Table 1 are at different levels of development and application in real life situations. Some of them are already commercialized and others still at their nascent developments. It is important to note that while most of the technologies might not have their origin from the construction sector nor being construction specific, each of them impacts in driving construction innovations. The technologies are broadly grouped into two categories, namely, the hard and the soft technologies. This grouping is based on tangible (which can be handled) and non-tangible innovations (consisting programs and algorithms). In each, there are a number of innovations that have been achieved. This work identified and discussed 21 in all with 10 as hard technologies and 11 soft (see Table 1).

Table 1: Technologies driving construction innovations 4.0

	Hard technologies	**Soft technologies**
1	Sensors (Ssr)	Building information modelling (BIM)
2	Exosuites Es	Cloud computing (CC)
3	Drones (Drn)	Big data (BD)
4	3D printers 3Dp	Artificial Intelligence (AI)
5	Robots (Rb)	Machine Learning (ML)
6	Virtual Reality (VR)	Deep learning (DL)
7	Augmented Reality (AR)	Digital Twins (DT)
8	Holograms (Hg)	Machine to Machine Communication (M2M)
9	Autonomous Vehicles AV	Internet of Things (IoT)
10	Smart Materials (SM)	Block Chain (BC)
11		Quantum Computing (QC)

Source: adapted from Statsenko, Samaraweera, Bakhshi and Chileshe (2022).

Hard technologies application in construction 4.0

This category of innovations consists of physio-tangible inventions that users relate on physical basis for on-site and off-site construction procurement tasks. The technologies come in different forms, shapes and sizes ranging from small to large equipment.

Sensors (Ssr): sensors are physical devices that can detect, perceive or sense changes in an environment or any physical quantity or energy and subsequently cause a reaction. The change in the environment could be heat, sound, light, motion or pressure. Many kinds of sensors relevant to construction are used in form of either component or image based to perform different sensing tasks, such as gather and communicate data for modelling purposes (Sanda, Abdel-Qader, & Akanmu, 2014; Sepasgozar & Shirowzhan, 2016). Data are collated through real time monitoring, location and tracking operations such as tracking vibrations, structural health of facility, logistics and automation (Zhang, Chen, Wang, Tang, Sun, Huang, and Wang, 2021, Rao, Radanovic, Liu, Hu, Fang, Khoshelham, Palaniswami and Ngo, 2022, Charahjanloo, 2023).

Exoskeleton (Es): this is a wearable, external mechanical structure that enhances the capability of a person in carrying out tasks (Yeem, Heo, Kim and Kwon, 2019). It is either a full-body or part-body worn device meant to enhance job capability. In construction, one can lift heavier loads, do repetitive jobs easier and stay longer on tasks without fatigue. Apart from quality jobs and safety, these wearable technologies (Rosman and Mahmud, 2021) can be feed with sensors that synchronize data with mobile devices, be assigned the attributes of mobility and connectivity to wearers for online access to information and ensure real time communication with others while functioning. Yeem, Heo, Kim and Kwon (2019) predicted the autonomous path finding and automated walking exoskeletons that can self-navigate through obstacles without user's assistance.

The 3D printer (3Dp): this is a machine that uses additive manufacturing principle to create the physical three-dimensional solid object from a digital form (Prakash, 2014, Lund-Nielsen, 2022). The digital format stored in a computer is read by the machine and printed out in the physical form. The introduction of this machine in construction is a major breakthrough against the complex construction characteristics. A pedestrian bridge in China, one, two and three storey buildings in Germany have been printed, all done within very short period compared to the conventional system. Materials and components are also printed on site if so desired (Lund-Nielsen, 2022).

Drones (DR): drones are also known as unmanned aerial vehicles (UAVs) meaning that it is a flying aircraft without human beings inside it to operate. The control system for tasks performance is either done by an inbuilt computer programmed system or remotely controlled on the ground by someone near or far away. Drones in construction are viable agents that are sent to run errands on data collation and monitor of relate real-time site information such as providing up-to-date birds-eye view of a site (Dupont, Chau, Tashrif, and Abbott, 2017). Drones are used at the planning; construction and post-construction stages of projects. Tasks achievable include site survey contour mapping, site progress monitoring, construction quality management, etc. (Mahajan, 2021).

Robot (Rb): is a highly automated machine programmed to behave with intelligence, either fixed in place or mobile. Three measures of what a robot constitutes include-sense, think and act. It means a robot have sense to perceive its surroundings, collate data, uses the data to model its behavior and then perform assigned tasks that affects the physical world. Robots are already applied in construction for demolition, concrete pouring, spray coating, steel positioning, onsite masonry construction, and precast units manufacturing. (Akshatha, Vimala, Sahana, Manjula, 2017, Kathe, Lunawat, Mane, Wadhonkar, and Shaikh, 2022).

Virtual (VR) and Augmented Reality (AR): this is a technology that creates a virtual environment and takes an individual to the environment where he can interact and feel real. At the Virtual environment (VE) (Shiratuddin, Thabet, and Bowman, 2004) one walks-through and freely view 3D scenes from a first-person perspective and also gets immersed in this artificial world that exists only in the computer. In construction application, the technology enables a live, imitative version of the real world at site visits for monitoring and evaluation without physical presence, perform construction assembly prior to actual implementation, tests and modify the components of the facility to detect any error before actual construction work, touring of the finished facility for inspection and assessment without physical presence (Jain and Kokate, 2017).

Holograms (Hgm): also called virtual imaging technology is a new form of projecting images for presentations. The technology manipulates light in a special way to create an image that looks real and almost touchable (Zhou, and Zhang, 2020; Barnes, 2024). In contrast to the traditional 2D screen or wall projection, the image hangs in the air in 3D effect for all customers to sit round and obtain equal interaction and experience. Construction has found three main applications of holograms. These are the optical holographic prints where an existing building can be projected, computer generated holograms in which when the digital model of a building or part of it is developed a computer-generated hologram can be created; and lastly the volumetric 3D display that is interactive and enable users to freely navigate the model being projected. These are important in planning, monitoring progress and onsite clash detections (DaValle and Azhar, 2020).

Autonomous vehicles (AV): This is a concept of vehicles that drive themselves and maneuver their ways through obstacles without the need of a driver. The technology uses remote sensing devices like Radar, GPS, Cameras and light detection and ranging (LIDAR) to monitor and create a 3-D map of their environment. Streets infrastructure, other vehicles, pedestrians, traffic lights and road signs are captured in the environment. A powerful computer then processes the data and decides the operation by constantly adjusting the steering, speed, acceleration and braking while the sensors provide up to date situation of the vehicle's surroundings.

The SMART materials sciences: These are materials that respond to changes called stimulus in their environment (Bhalekar, and Dubal, 2021). Apart from being smart, they are described as intelligent. The science of material management has occurred in diverse architecture, engineering and construction research fields. Key concerns are material cost control, quality production, lean construction, site organisation, supply systems, waste management, etc. Producing competitive construction products through reduced wastes, controlled proliferation, prevention of damage, inventory management and minimisation of rework especially as it affects materials functions have been key efforts of stakeholders. Quality material function is found to have great effect on life-cycle cost especially when it relates to the maintenance cost of facilities. There is a promising sign that the increased use of quality materials through smart materials in construction business will address most anomalies and reduce the burden of human attendant efforts in construction.

- These materials are smart because they sense any change in the environment and respond to it in an optimal manner. They perform both sensing and actuating functions and adapt to change in the environment (Konarzewska, 2017).

- They are intelligent because the respond to various external stimuli can be conducted in a regulated manner (Mohammed, 2017). The properties that change in response to external stimuli is predictable or controllable. The emphasis is "seamless quickness- immediate action for specific response (Konarzewska, 2017). As such, not every smart material is intelligent. The encompass of intelligent materials are many. The materials may be chromic, luminescence, rheological, astrictive, etc. (Abboob and Al Ghanimi, 2019). These materials can be self-healing, adaptive to environmental changes, etc. which offer construction advantage in terms of aesthetics, shading and longevity of elements.

Soft technologies application in construction 4.0

This relates to software programs and algorithms that cannot be physically handled but are rather installed in machines to help it function as desired. It gives a physical machine a form of intelligence to enable it act as desired. Many researchers believe that it is the soft technology that is actually defining the IR4.0 along construction innovation 4.0.

Building information modelling (BIM): this is an ICT platform where different software packages are hosted onto it for management solutions (Mbarga and Mpele, 2019). It is a cross-disciplinary collaboration, communication and risk management system that links all stakeholders together at different locations to work for a common construction goal (Wierzbicki, de Silva and Krug, 2011, Chan, Olawumi, and Ho, 2019). A 3d model of a facility can be created and shared among stakeholders for its management from conception, design,

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production and demobilisation. Any modification of the shared model by any member is reflected in real time before all others. The "nD" modelling, allows adding an almost infinite number of dimensions to the platform to perform construction tasks.

Cloud computing (CC): This concept gained traction around 2006 and 2007 (Bento and Bento, 2011). In a simpler and broader form, it is the act of getting some IT services from the internet, which is the cloud, instead of creating them. In this case, computing facilities are being made available as services offered by reputed vendors for users to access whenever and wherever they need it, in large or small volumes in exchange for some nominal payment for it (Bhowmik, 2017). The advantage is being reliable and available at any time, getting a shared pool of configurable computing resources from all existing technologies without the need for deep knowledge about or expertise with each one of them (Salazar, and Silvestre, 2017).

Big data (BD): decisions are better reached with supportive facts and figures. In a dynamic world, data offer the facts and figures for quality decisions along emerging necessities. Advancements in ICT have revolutionized data generation, management and analysis. Large quantity of data is now generated each second in structured, semi structured and unstructured forms from social media, sensors, smart mobile devises, images, videos, and many others. (Zulkarnain and Anshari, 2016). The data analytic process provides meaning to the bulk and variety of data acquired and fed to demanding systems. Data storage capacity is enhanced through (Arora and Goyal, 2015) grid computing where different servers are interconnected through high-speed network and each server performing a particular or more functions. It is offered on demand in two dimensions i.e. as either Service generated Big Data or Big Data as service (Arora and Goyal, 2015). Construction is a massive data generating client. From its lifecycle, characteristics like myriad operations, many stakeholders, diverse changes and decisions, location factor, facility operation, etc. often generated a lot of data. Knowledge capital flight might be a thing of the past (Verdenhofs, Geipele and Tambovceva, 2019).

Artificial intelligence (AI): Artificial Intelligence (AI) is the ability of a machine to perform tasks often done by humans. Intelligence itself is a combination of capacity or logic, understanding, self-awareness, learning, emotional knowledge, reasoning, planning, creativity, and problem solving (Robinson, 2018). It means that AI machines can execute tasks and solve problems similar to human intelligence (Kulkarni, Bagewadi, Desai, and Kulkarni, 2021). AI machines analyse their environment, acquire and correctly interpret data, learn from the data, and use those learnings to take actions to accomplish specific goals and tasks through flexible adaptation (Kaplan & Haenlein, 2019, Holzmann, and Lechiara, 2022). These characteristics are great potential in preconstruction, construction operations and asset management application. AI self-driving construction machines are already welding, laying bricks, laying tiles and pouring concrete with little or no help from humans.

Internet of Things (IoT): one great measure of human intelligence is communication accompanied by action. If a machine can talk to a machine or a human being can talk to a machine and to objects, vice versa, then a great milestone is achieved in human history. A combination of digital innovations called IoT (Woodhead, Stephenson and Denise Morrey, 2018) which began around 2008 and 2009 enables this (Salazar and Silvestre, 2017). It means anything, biological and non-biological, can be connected to the internet for information exchange and communications in order to achieve smart recognitions, positioning, tracing, monitoring, and administration (Patel and Patel, 2016). IoT sends data in form of instructions or commands that tells an actuator or other physically connected devices to act or to control a physical process (Gunturi, 2021). In construction, it facilitates structural health monitoring, Real-Time Construction Management Solution and remotely control automated equipment (Guturi, 2021).

Machine Learning (ML): Just as human beings learn from their past, using experiences and analysed data to take decisions, machine learning (ML) which is a subfield in AI allows machines to behave similarly. It enables machines (Brooks, 1991) to mimic the reasoning process of human brain through induction, summarization, and internalization. In construction application, the ML algorithm makes AI learn from large amount of data and rules generated in the procurement process to make better informed decisions in executing complex tasks.

Deep Learning (SL): Deep learning is also an aspect of machine learning but uses artificial neural network (ANN) to mimic the structure of how human brain works. As a result, they acquire self-learning capability and take decisions without human assistance. Fundamentally, they are not explicitly instructed on how to solve a problem, rather, they understand models and patterns, and then apply them on situations. Elghaish, Matarneh and Alhusban (2021) stated that DL is employed to predict outcomes, determine places and quantities of resources on site, manage the use of multiple equipment in crowded construction sites to avoid clashes.

Digital twins (DT): there is now a link between a physical object and its digital form. When a physical object is connected to its virtual or digital representation it is called digital twins (Azeez and Adjekpiyede, 2022). The main stay of DT is the bidirectional integration with full data exchange between the existing physical object and its digital form, such that a change made to the physical object automatically leads to a change in the digital object and vice versa (Fuller, Fan, Day and Barlow, 2020), thus, contrasts other forms of digital representations like digital models and digital shadows. The virtual twin continually adapts to the operational changes of the physical asset based on data and information update and can predict the future of the physical counterpart (Liu., Meyendorf and Mrad, 2018). In construction, a digital model can relate to either an existing, on-going or future work (Ammar, Nassereddine, AbdulBaky, AbouKansour, Tannoury, Urban and Schranz, 2022). It is applied in automated progress monitoring of process implementation, update of as-built drawings/models, resource planning and logistics, safety monitoring, and even the remote control of physical objects (Government office for science, 2021, Madubuike., Anumba and Khallaf, 2022).

Machine to machine (M2M) communication: the transfer of data from one machine to another through wired or wireless technology is often initiated by human beings. The amount of data, kind of data, and destination device are determined by the initiator. A soft technology is already advanced to enable machines do the same, i.e. machines communicating autonomously end-to-end without human intervention which is known as machine-to-machine communication (M2M) (Booysen, Gilmore, Zeadally and Rooyen, 2011). The wireless aspect of M2M communication is gaining traction due to its flexibility, and billions of machines can be connected together to communicate and share data (Booysen et al. 2011).

Block chain technology (BC): This is a new type of database having digital records of transactions which is a decentralized and distributed ledger technology that provides information to be recorded, maintained and shared by a community. It is secured such that none can erase or change a transaction history. This therefore combines transparency, immutability and security for the participants of the network. The need for security, record of transactions, transparency in the construction industry 4.0 is achieved under the block chain technology. It is a consensus of shared and synchronized digital data geographically spread across multiple sites, countries or institutions, as such no central administrator or centralized data storage (Wu et al., 2017). The variety of construction material produced from different parts of the world and used in a variety of places deserve ways to reassure the sustainability of the materials throughout the supply-chain (Pryke, 2009), improved traceability and transparency in order to verify the quality of the materials (Hultgren and Pajala, 2018).

Quantum Computing: Quantum computing represents a transformative leap in computational capability, utilizing quantum bits (qubits) that exploit superposition and entanglement to perform complex calculations exponentially faster than classical computers for specific problems (Kanamori and Yoo, 2020). Unlike traditional computing, which processes information in binary states (0 or 1), quantum computing has the ability to handle multiple states simultaneously. As Construction 4.0 emphasizes digitalization and data-driven decision-making, quantum computing could significantly enhance the efficiency and accuracy of existing soft technologies. As an enabler of advanced computations, it will complement technologies like AI, machine learning, and digital twins, potentially leading to more efficient, sustainable, and innovative construction workflows.

The quantum computing technology is still developing. When it is fully integrated into Construction, its varying arms could redefine how projects are planned and executed. It can address optimization challenges, such as scheduling, resource allocation, and supply chain logistics through algorithms like the Quantum Approximate Optimization Algorithm (QAOA). These algorithms could identify optimal solutions more efficiently than classical methods, reducing project delays and costs. Further, Quantum Simulation could

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revolutionize materials science by modeling quantum mechanical systems directly, enabling the design of innovative construction materials with enhanced durability or sustainability. The Quantum Machine Learning could accelerate the analysis of vast construction datasets, thus, improving predictive maintenance, risk assessment, and decision support systems. The Quantum Cryptography offers theoretically unbreakable encryption, enhancing cybersecurity for sensitive project data in an increasingly connected construction environment.

DISCUSSIONS

It has been made evident that construction has increasingly rely on technology in its developmental strides. Beginning from its cradle, many technologies have brought about innovations that disrupted its arts and sciences. Today, appreciable changes have occurred and is still occurring in the procurement process. Figure 3 summerises the trend of construction dependency on technology innovations over its historical development.

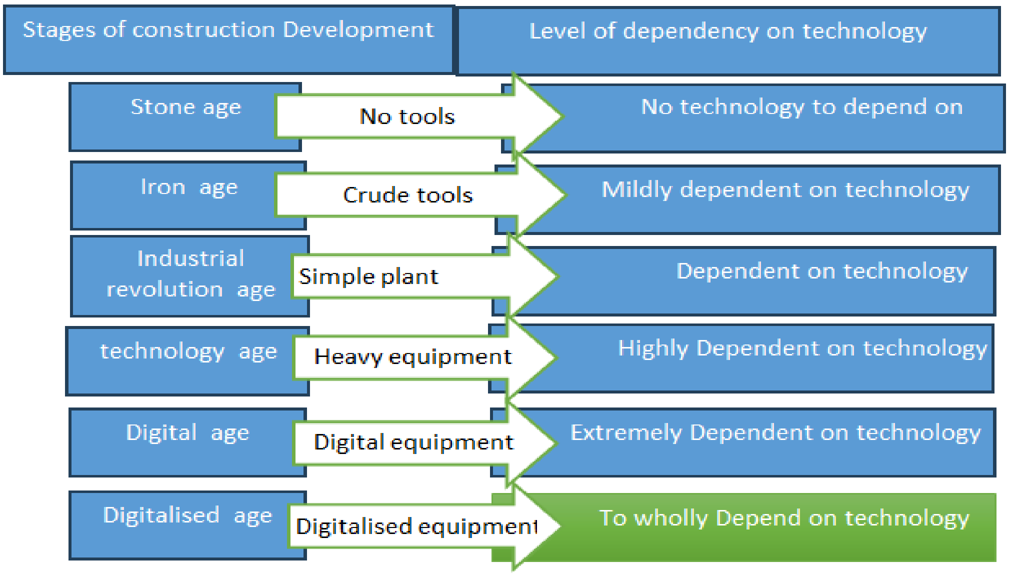

Figure 3: Dependency of construction on technology

Construction is a process which brings about a tangible product. Figure 3 depicts the developments in technology and application in construction process. It suggests that machines have increasingly been applied and are already set to undertake most tasks thought to be intelligent human exclusive. The construction work flow from inception to closing is being progressively overtaken by intelligent machines as observed by Boton and Forgues (n.d). At the digitalized level, it suggests that human input in construction procurement may be minimal or the process may wholly depend on technology.

Generally, construction has four stages, preplanning, planning, construction and closing. Each stage consists of a set of activities that contribute in bringing the product into actual existence. The construction process flow and some key activities at each level are presented in Table 3. The essence of this table is to depict the process flow in construction and the key tasks at each level, and also indicate the relevant construction 4.0 tools that can be applied.

Table 3: Application of innovative technology tools in construction workflow

Stage	Work flow process	Task	Tools
Pre planning	Supply chain	Setting up a team of supply chain to receive brief	• Virtual reality (VR)/ Augmented reality (AR) • Internet of Things (IoT)

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	Feasibility study	Establishing the technical, economic and social viability of the proposed project.	• Artificial intelligence (AI) • Machine learning (ML) • Big Data and analytic (BDA)
Planning	Site visits and survey	Gathering data on site features like topography, access roads, adjacent structures, social amenities, etc.	• Drones • VR/AR • BDA
	Designs and models	Architectural, engineering designs and modelling	• BIM, • Digital twin (DT)
	Estimating	Prepare bill of quantities, schedule of materials needs, and program of work.	• Building information modelling (BIM) • Block chain technology (BCT) • BDA, • Cloud computing (CC)
	Site mobilization	Site organization, assembling of equipment, material delivery	• AI, • Machine to machine communication (M2M), • Autonomous vehicles (AV) • IoT
Construction phase	Setting out	Interpreting the design and marking the construction lines on site	• AI, • Robots, • Autonomous Vehicles (AE)
	Site clearance	Removal of obstructions and turf	• AE • Robots
	Excavations	Digging of trenches and column bases, removal of excavated material	• AE • Self-driving vehicles (SDV)
	Assembly	Erecting the carcass with concrete, blockwork, reinforcements, fixing components	• 3D printers • Robots • AI
	Finishes	Rendering, painting and decoration, tiling, ceiling	• Robots

		finishes	• ML
	Monitoring and control	Site safety and security, inspections of faulty work, corrections.	• Sensors, • drones, • DT • Deep learning (DL)
	Progress reporting	Report on the stage of work Physical progress inspection	• Hologram • Drones • VR • AR
Closing	Handover of facility	Inspection of facility, digital presentations, handover.	• Hologram • VR • AR • DT
	Demobilization	Removal of equipment and house keeping	• Robots • AI • Self-driving vehicles (SDV)
	Occupation		• DT • CC • Sensors

Table 3 has also depicted a detailed classification of the innovative technologies based on the stage each can be applied which avails better understanding of the performance and application of each invention. The classification herein therefore is based on the performance of each invention in construction procurement as reported in literature. Some of the technologies, even though designed for a particular purpose, can perform multiple functions in construction. This classification should facilitate easy choice of relevant tool that can best accomplish a construction task and most suitable for a particular purpose.

The future of construction production flow

At the digitalised stage, construction 4.0 is on the horizon. One objective of this work is to predict what happens to construction flow system at this stage of scientific innovations looking at the trend related to the technological advancements already on the ground? Intelligent machines are being invented to imitate human beings. Evident from Table 3 is that, at the full arrival of construction 4.0, the disruption will see construction flow relying almost entirely on machines. It means, it may be difficult to have significant human labour in the construction production flow system. In other words, all construction stages will be overtaking by machines. Man may only be engaged in managing the machines, and even then, how about if machines can manage themselves?

In the conventional construction flow system, the first stage is the initiation where the client engages and manages a supply chain at the inception of a project. The client briefs the team of experts who develops the brief and comes up with a feasible proposal. The feasibility study is conducted to ensure the viability of the proposed project. Intelligent machines today can produce the proposal from client's brief without human assistance. The proposal and feasibility study which ascertains the economic, technical and legal practicability of proposals can be handled through the use of technology like the interconnectivity of big data with BIM and AI. Also, drones visit sites to communicate real time site information and autonomous vehicles maneuver their ways to sites for physical presence during site exploration. They can harbor in-situ soil testing machines and interpret the soil conditions. Soil samples for offsite laboratory test are more accurately taken to get whatever variables demanded offsite. Site visitations are achieved by the VR/AR conveying team members for an immersive real-world appearance even without leaving the office environment for such 'actual' presence. The work of the client in the future under this stage will essentially be to manage relevant machines for the conduct of the pre-planning functions.

The next stage is the planning for the project where consultants produce detailed architectural and engineering designs, electrical and mechanical drawings, bill of quantities and bids documents and invite bidders to compete for the selection of a competent builder. Connecting this stage to the pre-planning shows that the need might not be pressing because intelligent machines can generate every detailed requisite design at the onset. The main function of the bill of quantities is to enable competitive bidding to identify competent builder. If there is a machine that can carry out the assembly process it means the need for a human builder does not arise which eliminates the bidding functions. The bidding here may involve only the state of arts of equipment. However, the material schedule function to establish the quantity of materials requirement for the machines to work may be necessary here to make the client supply financial requirement. With the detailed sketches an AI machine can produce such materials schedule. This still reduces the need of human input in the function.

The construction stage is the level in which the facility is assembled based on the designs and specifications. This is the level that a contractor mobilises material, labour and equipment to site to raise the structure for a tangible real facility. Autonomous vehicles and robots with AI blending may maneuver their ways to bring whatever material and deliver the equipment needed for the project to site. The loading and offloading of these items will be possible and site organization may be carried out more efficiently. However, humans may be required to set up some machines in position like the 3D printer, depending on the level of technological advancement. The 3D printers are already printing physical construction facilities based on the designs and specifications stored in digital format. There are several kinds of printers assisted by dedicated robots that can achieve such contractor functions. The big data, machine learning and deep learning programs may help robots in decision making to solve emerging site challenges and bring up a facility that is functionally and aesthetically viable. The M2M communication initiates and communicates data and whatever information required for the project which was an exclusive function of humans. Monitoring and control can be achieved through digital twins that presents ongoing changes digitally as the assembly progresses. Drones also make it possible to relate on-going activities, VR/AR enable site visits. This helps in real time human information and communication on the changes on the project; this is despite possibility for managers to instruct the machines on site through biology to machines interconnections. The closing out stage hands over a constructed facility to the client for occupation. Usually, site visits for the purpose of touring the facility to inspect elements' completion level, assess quality, undertake housekeeping, prepare as-built document for maintenance needs of the occupied facility are the main activities carried out at this final stage. It is clear that machines will easily achieve these functions. The VR/AR enables immersive site presence for human eyes inspections. Beyond that, the Digital Twin offers maintenance information and tracks down up-to-date deterioration data at real time in the life of the facility for maintenance purpose. As the facility deteriorates it is reflected on the digital representation in the DT technology. When SMART materials technology becomes advanced, elements can heal themselves in quick secession when faults occur. This reduces the rate and extent of damages to a facility by virtue of delayed maintenance which will extend the physical life of the facility.

As construction workflow becomes increasingly automated, the computational demands for real-time decision-making, optimization, and predictive analytics will escalate. Quantum computing, with its unparalleled ability to process vast datasets and solve complex problems rapidly, could serve as the backbone for these intelligent systems. By powering advanced algorithms for AI, machine learning, and digital twins, quantum computing may enable machines to autonomously optimize construction processes, predict potential issues with greater accuracy, and enhance overall project efficacy and sustainability, pushing the frontiers of Construction 4.0 with a reality in fully digitalized and autonomous future. While Construction 4.0 is already transforming the industry through digitalization and automation, quantum computing stands on the horizon as a technology that could either enhance IR4.0 or usher in IR5.0. Its ability to solve complex problems and process vast amounts of data could redefine construction workflows, making them more efficient, sustainable, and innovative. As the industry prepares for this potential shift, professionals must consider how to adapt to a future where quantum computing plays a central role.

Finally, this work has assessed the technological advancements and their implications on the construction work flow, management and the technological sub systems. The pertinent question is what will be the role of the professional team under industry 4.0 and whether the era is a blessing or disadvantage to the construction professional callings? Furthermore, will the advancement in quantum computing give rise to a new industrial revolution (IR5.0), or will it perfect IR4.0?

CONCLUSIONS AND RECOMMENDATION

Construction has increasingly depended on technological advancements on a steady note. Since its cradle till date various eras have been synonymous to introduction of advanced technologies. For each stage such innovations have disrupted construction production flow system.

This work has insufficiently appraise the technologies driving construction 4.0 era and the impact of the era on the construction procurement system. There is a wide range of technologies at the construction 4.0 stage and each technology has distinct characteristics that drive construction production. In this paper, the technologies have been identified together with their relevance in the production work flow. This paper has therefore brought about better understanding of the technologies and their implication in the construction 4.0 era which should guide the choice of technology at each stage of the construction procurement. The prediction of the nature of future construction workflow has also been presented. It is evident that the contribution of many construction experts to construction planning and assembly may be insignificant. As machines mimic human intelligence, there will be little human contributes to construction since the machines may most likely produce better competitive quality products in real time. Human contributions will be more on the knowledge of the new technologies. This work has contributed to literature in the subject in question.

It is recommended that stakeholders in the industry should prepare against the full introduction of construction 4.0. Many innovations are already on the ground to push the frontiers of this era. Sooner or later, contractors will only compete if they acquire the technology relevant to construction 4.0. Construction professionals should begin to think and reconsider their roles in construction procurement in the near future as machines are most likely to execute their tasks. Investors and contractors get set to invest in this cutting age and competitive technologies that is real, as construction is likely to be cheaper, safer, quicker and more qualitative than what is obtained today. It is recommended that the cost implication of achieving a complete construction 4.0 system be assed even though the cost of the innovative machines may fluctuate based in the level of technological advancements, demand and availability.

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