APPRAISING COST CONTROL METHODS, TOOLS AND TECHNIQUES IN INDUSTRY 4.0 ERA

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Abstract

Cost overruns have been a major source of concern to project clients and other project stakeholders for decades. The consequences of cost overruns include reduced guaranteed profits for the contractor and several additional issues for all stakeholders, including additional delays, contractual disputes, claims and litigation, inefficient allocation of scarce resources and project failure or abandonment. To address these problems, it is essential to establish effective cost control strategies to ensure projects are executed within budget. Several methods, techniques and tools have all been put forth to aid construction cost control. The increased usage of Information and Communications Technology (ICT) as well as digitalization and automation have fuelled the evolution of the fourth industrial revolution (Industry 4.0). The futuristic idea of Industry 4.0 is centred on digitization of a product's value chain and the enhancement of productivity using a technologically diverse and industrialised automated manufacturing environment. However, there appears to be a paucity of scholarly research on the role Industry 4.0 technologies in supporting construction cost control. This research aims to appraise the existing methods, tools, and techniques for construction cost control with a view to identifying a more robust approach that meets the 21st century challenges especially in the era of Industry 4.0. This will be accomplished by conducting a comprehensive literature review which will classify the findings according to three main themes: methods, tools, and techniques of cost control. This will inform how to improve cost control of projects in the era of Industry 4.0.

Keywords: *Information and Communications Technology (ICT), Industry 4.0*

1. Introduction

The construction industry encounters several fundamental obstacles, such as cost overruns, project delays, and inefficient performance, despite the rapid pace at which technology and digitalization are advancing (Linderoth, 2010; Yismalet & Alemu, 2018). These fundamental obstacles of the construction industry have been criticized due to the involvement of various stakeholders, lack of coordination, high risk and uncertainty, and inadequate resource integration and data exchange (Zhiliang et al., 2004).

It has been observed that construction projects in the developed, as well as developing countries frequently exceed cost estimates, with an 86% probability, according to Flyvbjerg et al. (2002).

Consequently, cost overruns in rail projects (45%), bridge projects (34%), and road projects (20%), leading to decreased investment effectiveness and a requirement for additional funding (Cunningham, 2015). Additionally, cost overruns on public works contracts have a negative impact on the economy by draining resources away from other projects (Li et al., 2021). In extreme circumstances, this could lead to the failure of the project or the business (Hongtao, 2014).

The practice of ensuring that the price of the contract falls within the budget allocation of the client is known as cost management (Potts & Ankrah, 2013). Quantity surveyors (QS) play a critical role in cost management by estimating the possible cost of a building project and advising clients on cost and quality standards early on in the process (Cartlidge, 2013). Cost control is a crucial component of construction cost management, which involves ensuring that the final cost of construction does not exceed the client's budgeted allocation. This is achieved through identifying cost variations, analysing favourable alternatives, and implementing appropriate actions (Lu et al., 2018). However, studies have shown that construction organisations face several challenges during cost control, certain barriers such as use of obsolete methods and concepts, inadequate access to software packages, putting too much emphasis on outcomes while disregarding the cost control process, reoccurred in most of the studies, irrespective of their location (Adjei et al., 2017; Bergerud, 2012; Igwe et al., 2020; Keng & Adzman, 2015).

Over the years, various cost control methods, techniques and tools have been established for the sole purpose of improving the efficiency of cost control. These methods include Work programs, Unit Costing, Cost Estimating and Budgeting, Leading parameter method, Kaizen costing (Akeem, 2017; Granja et al., 2005; Olawale & Sun, 2010; Olawale & Sun, 2015) and more recently Building Information Modelling (BIM), and others (Alrashed & Kantamaneni, 2018; Eastman et al., 2011). Similarly, techniques such as Interim valuations and certificates, Post project reviews and site meetings, Program Evaluation and Review Technique (PERT), Cost-benefit analysis, variation/change management have been developed (Ashworth & Perera, 2015; Oladapo, 2007; Olawale & Sun, 2010; Omotayo, 2017). Additionally, tools like Microsoft Project, Primavera, Onscreen take-off, QS Plus, WINQS, Master Bill, etc. have been established. These software packages can be utilized together with the techniques outlined above (Owens et al., 2007).

The concept of Industry 4.0 (4IR) has recently garnered significant interest in the manufacturing sector, with the goal of enhancing digitization, automation, and ICT deployment (Kurniawan et al., 2022). The primary goal is to establish a digital value chain spanning the entire product lifecycle, from conceptualisation through use and recycling (Lasi et al., 2014), resulting in high-quality products, shorter time-to-market, and lower costs, leading to an improvement in business performance as a whole (Brettel et al., 2017). The adoption of 4IR is typically driven by the integration of foundational and advanced technologies. Foundational technologies, which include the Internet of Things (IoT), cloud computing, big data (BD), and advanced analytics such as artificial intelligence (AI), serve as the foundation for digital operations (Frank et al., 2019; Meindl et al., 2021). They support the application of other advanced or front-end technologies like additive manufacturing (AM)/3D printing, BIM, digital twin construction (DTC) and advanced robotics (Frank et al., 2019; Meindl et al., 2021). While these technologies have already made a significant impact on several industries, 4IR's potential is yet to be fully realized. The construction sector, commonly referred to as Construction 4.0 in light of 4IR, is an example of a sector that has only partially implemented the technologies mentioned earlier (Begić & Galić, 2021).

Academics and practitioners have recently shown a growing interest in Construction 4.0., evidenced by the rising number of studies on the subject. Various attempts have been made to categorize construction with the Industry 4.0 framework. For instance, Oesterreich and Teuteberg (2016) recognized a number of key concepts and technologies within the Industry 4.0 framework for the construction domain and divided them into three primary groups: simulation and modelling, smart factory, digitization and virtualisation. Dallasega et al. (2018) identified six major study areas related to Industry 4.0 concepts that are relevant to Construction Supply Chains (CSC) including BIM, 3D printing, cloud computing, digitalization, tracking and localization, and e-supply chain management. In another intriguing and enlightening literature review focusing on Construction 4.0, Boton et al. (2021) presented over a decade-long map of research topics and clusters. The research found that BIM was the most commonly cited keyword and highlighted that AR and VR are also pertinent to the Construction 4.0 concept. Despite BIM's numerous benefits being widely acknowledged, the construction industry us yet to tap its full potential in the construction industry, particularly during the post-contract (construction) stage of projects. Even though BIM is frequently used during the design stage of construction projects, it remains poorly integrated in the implementation phase, i.e., on-site implementation.

However, there is paucity of studies in the role Industry 4.0 technologies in supporting specific construction management processes like construction cost control. Therefore, this research aims to appraise the existing methods, tools, and techniques for construction cost control with a view to identifying a more robust approach that meets the 21st century challenges especially in the Industry 4.0 era. This paper's subsequent sections are organised as follows: Section 2 will present a comprehensive overview of current methodologies, tools, and techniques employed within the domain of construction cost control. The literature review on 4IR will be discussed in Section 3, while Section 4 will focus on the Construction 4.0 paradigm. In Section 5, an analysis of construction cost control in the context of Construction 4.0 will be presented in details. Finally, in Section 6, the conclusions will be drawn for the study.

2. Overview of Construction Cost Control

Project cost performance is typically a critical factor for all construction stakeholders. Typically, cost overruns and inability to finish work within the stated budget are frequently the source of the most troublesome construction conflicts (Alghonamy, 2015). Cost overruns are a global occurrence, however the circumstances vary from country to country (Ahady et al., 2017). The variation is influenced by a variety of economic, geographical, and construction related factors that vary per country. Factors such as the intricacy of construction, the involvement of numerous stakeholders including contractors, consultants, end users, project owners, financiers, and project funds, as well as considerations regarding materials, equipment, economic, climatic, and political environments, all contribute to this variation (Ahady et al., 2017).

Hence, a significant number of construction projects across the globe fail to achieve their project cost objectives, leading to cost overruns (Azhar et al., 2008; Niazi & Painting, 2017). To the client, as described by Nega (2008), cost overruns imply additional costs beyond those first agreed upon, resulting in lower returns on investment. For the contractor, this leads to reduced profits due to non-completion and harm to their reputation, which could affect the contractor's chances of receiving more jobs if at fault. Regardless of the professionals involved in a project, it suggests an inability of providing good value for money, potentially damaging their reputation and eroding client trust.

The construction cost overruns issue is a major concern in both advanced and emerging nations, as well as in both the governmental and business spheres (Memon et al., 2013). Aljohani et al., (2017) provide examples of several projects that experienced cost overruns, including Denmark's Great Belt Link project, which went 54% over budget, the United Kingdom's Humber Bridge project, which went 175% over budget, seven megaprojects in Korea, which went 122.4% over budget, and railroad projects in the United States, which went 61% over budget. In addition, Flyvbjerg et al. (2002) surveyed 258 transportation infrastructure projects of 20 countries across five continents, encompassing both developing as well as developed countries. The results of the survey revealed that 86% of the projects encountered cost overruns, averaging a cost overrun of 28%. The foregoing illustrates the severity of cost overruns in both developed and developing economies. Numerous methods, techniques and tools for construction cost control have been developed and implemented as illustrated in Table 1, to address the issues identified with the construction cost control process. Table 1 shows the most prevalent existing methods, techniques and tools utilised for construction cost control.

Table 1: Cost Control Methods, Techniques and Tools

S/N	Method/Tool/ Technique	Description
Cost Control Methods		
1	Work programs (Otim et al., 2018)	Schedules are used by contractors to keep track of their work and financial performance. Since job progress can be measured and related to costs, it is an effective method.
2	Cost Variance (Unit Costing) (Olawale & Sun, 2010; Potts, 2008)	During and before construction, a single rate cost estimation method is used. Using this procedure, the costs of the various building elements are estimated.

3	Cash Flow Management (Ashworth & Perera, 2015; Kirkham, 2015)	The planning of a company's payment schedule and estimation of when income is anticipated to be received.
4	Earned Value Analysis (EVA) (Project Management Institute PMI, 2005; Webb, 2017)	Contractors primarily utilize EVA to monitor advancement of projects by regular comparisons of the anticipated expenses with actual costs.
5	Cost Reports (Fellows, 2008; Kirkham, 2015)	In cost reports, various components such as expenditures, profits, total costs, and final cost projections are included. . Senior management might use cost reports to gain an idea on the project's progression.
6	Cost Estimating and Budgeting (Ashworth & Perera, 2015; Fellows, 2008; Kirkham, 2015)	Involves predicting costs and establishing a predetermined budget that serves as a yardstick for comparing actual expenses. This process is utilized to assess project performance by evaluating spending against the established budget.
7	Value Engineering (Ashworth & Perera, 2015; Cheah & Ting, 2005)	A component of the value management process that identifies and eliminates superfluous expenditures while maintaining the same level of quality and performance.
8	Activity Based Costing (ABC) (Al-Hajj & Al Zaher, 2012; Cooper & Kaplan, 1988; No & Kleiner, 1997)	Identifies the indirect expenses (overhead costs) in order to determine their optimal allocations determined by the activities required to produce a particular service or product.
9	Cost-Value Reconciliation (CVR) (Olawale & Sun, 2010; Potts, 2008)	Identifies an accurate and realistic financial state at any given time by forecasting the company's profitability.
10	Leading Parameter Method (Al-Jibouri, 2003)	Is a technique that selects one or more of the substantial types of work as performance indicators for the entire project.
11	Kaizen costing (Granja et al., 2005)	A method for incrementally reducing construction costs by identifying and eliminating waste before it occurs.
12	Standard Costing (Hallbauer, 1978)	Is a systematic approach used to create a detailed set of cost standards that encompass all business activities. It involves comparing actual costs to these cost standards, thereby uncovering the underlying causes of any discrepancies in a comprehensive manner. By aggregating the variances, a complete profit and loss statement can be generated.
13	Target costing (Nicolini et al., 2000)	Refers to the process of limiting the cost of designing and constructing a capital facility to a predetermined maximum cost.

14	Building Information Modelling (Omotayo, 2017)	The system integrates construction experts involved in a project into multi-faceted computer software that compiles construction data (design, cost, and other pertinent information) on a single platform, hence facilitating the project delivery.
Cost Control Techniques		
1	Record keeping of cost information (Sanni & Durodola, 2012)	During construction cost control, data from similar past projects are utilised.
2	Site meetings and post project reviews (Ashworth & Perera, 2015; Omotayo, 2017)	In the concluding meeting together with the progress meetings held throughout the project, the topics of cost, expenses, profits, and variations are reviewed and discussed.
3	Interim valuations and certificates (Ashworth & Perera, 2015; RICS, 2015)	The process of evaluating the construction site work that has been performed and arriving at a mutually agreeable value for it by the contractor quantity surveyor and the client.
4	Monitoring project resources (Day, 1994; Kirkham, 2015; Omotayo, 2017).	Keeping a close watch on labour, equipment, and overhead expenses.
5	Incremental milestone (Construction Industry Institute (CII), 2000; Leu & Lin, 2008)	Utilized mostly for expense accounts that require subtasks that must be executed sequentially.
6	Cost-benefit analysis (Construction Industry Institute (CII), 2000)	A cost-benefit analysis that can be performed to assess the project's value during its valuation.
7	Program Evaluation and Review Technique (PERT) (Olawale & Sun, 2010)	This refers to a management tool used to schedule, harmonise, or coordinate work within a project and arrange them.
8	Variation/ change management (Ashworth & Perera, 2015; Oladapo, 2007).	This may refer to an increase, reduction, or replacement of the initial scope of work outlined within the building contract.
Cost Control Tools		
1	Manual measurement and recording using record cards and papers (Khan et al., 2017; Lin et al., 2013)	Scaling and calculations from project drawings, physical measurement, and recording of project data using measurement papers manually.
2	Microsoft Project (Narayana, 2019)	MS Project is widely regarded as a tool that assists organisations with project planning, budgetary allocation to appropriate tasks, project tracking, cost management, and capacity planning.

3	Primavera (Kumara et al., 2021)	Primavera has similar features like MS Project with other functionalities and is used for construction scheduling, cost, and time control of construction projects.
4	Onscreen take-off (Olivieri Olmeda, 2022; Wahab & Wang, 2021)	Traditional 2-D software for estimation, for instance On-Screen Takeoff, was created to provide estimators with a graphic depiction of measured materials.
5	QS Plus (Sepasgozar et al., 2022)	The QS+ software provides the capability to generate comprehensive Bills of Quantities, Cost Plans (Estimates), Valuations, and Final Accounts with detailed accuracy.
6	WINQS (Akinshipe et al., 2021; Harinarain et al., 2023; Ibironke et al., 2013; Olawale & Sun, 2015)	Allows the monthly review of a project based on the contract value showing all extras/ savings as the project progress to the final cost. It is a complete package for cost management
7	Microsoft Excel (Abdel-Hamid & Abdelhaleem, 2021; Akinradewo et al., 2021; Sepasgozar et al., 2022)	Commonly employed tool for planning, progress monitoring, and controlling construction project
8	Photo net II (Zhao & Wang, 2014)	This is an advanced tracking system that operates in real-time, utilizing digital imaging of construction projects based on time-lapse along with critical path method integration (CPM) and progress controlling methods to present a visual comparison between the planned and actual work schedules.
9	Master Bill (Sepasgozar et al., 2022; Wan & Pang, 2022; Zaia et al., 2022)	Masterbill is the comprehensive bill of quantities production system, that includes pricing, cost analysis, and tender comparisons.
10	Vector (Ibironke et al., 2013)	Used for construction measurement, estimation, analysis and generation of resources, valuation, cost reporting, etc.
11	Estimator^{pro} (Ibironke et al., 2013; Sepasgozar et al., 2022; Wahab & Wang, 2021)	Used basically for estimation of construction project activities. It has all the features of Estimator software including sub-contract and comparison routines.

3. The Fourth Industrial Revolution

In its largest context, the term "industrial revolution" refers to a period during which there was a significant upheaval in the processes that were used to manufacture goods and provide services (Fitzsimmons, 1994). As shown in Fig. 1, the printing press was the catalyst for the first industrial revolution, radio and television for the second, and personal computers, mobile phones, and convergence of computers, telephones, and television news broadcasting for the third (Troxler, 2014).

While a significant portion of the global population has yet to experience the advancements of the third industrial revolution, developed nations have already implemented the fourth industrial revolution (4IR) (Schwab, 2017). The 4IR, also known as "Industry 4.0," first appeared at the 2011 Hannover Fair (Sawhney et al., 2020). Schwab (2017) defined the 4IR as "a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres". Improvements in supply-side efficiency and productivity in the long run are projected as a result of technology advancements, as the 4IR progresses at an exponential rate, rather than slowly or linearly like the previous eras of industrial revolutions (Begić & Galić, 2021). 4IR refers to a new organisational level, development, and control of processes and products over their entire lifespan. To optimise processes in a coordinated and effective manner, it applies technologies to improving iterations of cutting-edge tools and techniques (Rivera et al., 2021).

Industry 4.0 includes upcoming industry advancement trends aimed at to achieving manufacturing methods that are more intelligent, such as dependence upon Cyber-Physical Systems (CPS), the development of Cyber-Physical Production Systems (CPPS), the Internet of Things (IoT), as well as implementing and operating smart factories (Zhou et al., 2015). As demonstrated in the following section, novel Industry 4.0 notions can be applied within the construction domain.

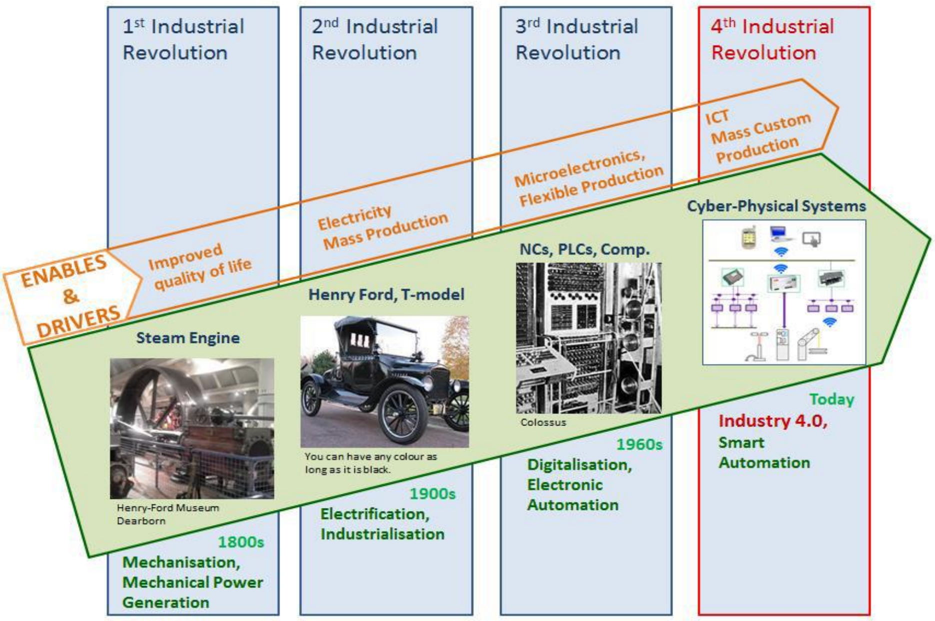

Figure 1: The Revolution of Industry from 1.0 to 4.0 (Source: (Chakraborty & Mandal, 2021)

4. Construction 4.0

In spite of the numerous definitions that are already in use and the absence of a specific standard, there appears to be a general agreement that "Construction 4.0" refers to the adoption of "Industry 4.0" to solve construction industry issues, or, digitalisation of construction in its broadest sense (Rivera et al., 2021). Construction 4.0 characterizes a novel paradigm that incorporates CPSs and IoT, data, along with services, whose objective is to connect the digital layer, which comprises BIM as well as the common data environment (CDE), to the physical layer, which comprises of an asset and the assest's lifecycle (Begić &

Galić, 2021). To achieve this, Construction 4.0 employs not only cyber-physical systems but also digital ecosystems that are linked to CPS as the main driving force (Rowsell-Jones et al., 2016). By emphasizing the capture of data in real-time and sensors integration into construction processes that are occurring on site, Construction 4.0 seeks improved quality control, worker safety, and optimized time and cost by automating and digitizing the processes of the design and construction stages (Alaloul et al., 2018).

In accordance with Industry 4.0, the construction sector is swiftly adopting various technologies like augmented reality (AR), virtual reality (VR), mixed reality (MR), and BIM at different stages of development (Hossain & Nadeem, 2019). These technologies are at different levels of development, with some like mobile computing, cloud computing, modularization and BIM having been around for a while and being commonly used, while others such as VR, AR, and MRs happen to be just in the early developmental stages (Begić & Galić, 2021; Hossain & Nadeem, 2019).

To comprehend Construction 4.0, four technologies were identified in a 2020 study: 3D printing, Big Data, VR, and the IoT. The study was executed by performing a bibliometric analysis as well as an examination of the frequency of the use of keywords (Forcael et al., 2020). Perrier et al. (2020) examined 4IR technologies implementation within the construction industry and discovered the preconstruction stage to be the centre of attention for the majority of the integrated solutions.

5. Construction Cost Control in Construction 4.0

Lu, et al. (2018) reported that keeping a project on budget track is dependent on the implementation of a system of cost control that is both efficient and successful. It should be feasible to extract useful information from the data created, not just to discover historical patterns, but also to estimate the likely consequences of future decisions, including the final account. Specifically, cost control measures include the following:

1. Develop a comprehensive cost control plan that identifies unfavourable trends, nonconformities, delays, and further project issues.
2. Evaluate and approve the project work breakdown structure.
3. Establish and track the cash-flow of the project.
4. Monitor and report on project costs throughout the construction phase.
5. Authorize and submit reports on finances to both the owner as well as contractor involved in the project.

Construction 4.0 is continually developing in tandem with the domain's research developments. This section covers the most prevalent Construction 4.0 drivers and their application to construction cost management.

5.1 Cyber-physical Systems (CPS) and Digital Twins (DT)

Cyber Physical Systems (CPS) refer to a collection of physical objects, devices, and equipment connected to a virtual cyberspace via communication network (Steinmetz et al., 2018). This allows for a digital version of every physical unit, also known as "Digital Twin," to interact with and monitor the actual equipment or system (Grieves, 2014). The Digital

Twin (DT) is capable of interacting with and monitoring the actual entity, equipment, or system (Schroeder et al., 2016). By incorporating physical entity with the corresponding virtual counterparts, context-aware, integrated analytical systems can be created that respond to modifications to the physical construction site or structure (Anumba et al., 2021). This is achieved using sensors and data gathering technology, as well as actuators to create closed loop or feedback systems. Ultimately, CPS bridge the gap between the virtual and actual physical systems by connecting them in real-time (Chen et al., 2015; Dillon et al., 2011).

To achieve more efficient and sustainable construction projects, the integration of physical components with their digital counterparts through bidirectional information flow enables the utilization of advanced technologies such as automation, 3D printing, UAVs, sensor networks, and robotics, VR and AR (Anumba et al., 2021; Sawhney et al., 2020). The built environment is becoming smarter and more digitally interconnected, which includes smart buildings, cities, and infrastructure (Shelden, 2018). These developments are creating Cyberphysical environments that rely on CPS.

The integration of CPS with construction projects allows for bidirectional information flow, facilitating the collection of cost-related data and resource management during project execution. This integration supports effective construction cost control by identifying variations in cost, assessing alternative options, and implementing suitable measures. Utilizing CPS and Digital Twin platforms enables automated on-site work measurements, allowing for real-time monitoring, simulations, and informed decision-making. This flexibility in adapting schedules based on the actual construction scenario enhances cost control by moving away from rigid predefined plans.

In conclusion, CPS and Digital Twin technologies play a critical role in realizing the objectives of Construction 4.0, which aim to achieve safer, more environmentally friendly, and efficient construction projects. By leveraging CPS and integrating them into the cost control process, construction industry stakeholders can benefit from real-time data analysis, enhanced resource management, and improved decision-making capabilities. This integration offers greater flexibility and adaptability, resulting in more effective control over construction costs and ultimately contributing to the successful execution of projects within the 21st-century construction landscape.

5.2 Internet of Things (IoT)

The incorporation of physical, software, and implanted technology into networked items characterises the Internet of Things. These elements are capable of interacting and cooperating in order to achieve a common goal objective (Atzori et al., 2010). According to Kumar et al. (2016), the IoT is comprises four distinct layers: the application, perception, network, and physical layers. For the application layer, smart cities, transportation, and homes are captured. While the sensory devices allowing communication among other objects are captured in the perception layer, which also refers to technologies. Moreover, network communication and coverage are what the network layer pertains to. Finally, smart appliances and other hardware devices are encompassed in the physical layer. Utilizing IoT technology in the construction domain offers various potential benefits, with a focus on accelerated decision-making by providing real-time data analytics (Gubbi et al., 2013; Ning & Xu, 2010).

Effective construction cost control relies on obtaining real-time and accurate feedback from building sites, managing various forms of data, and conducting data analysis to develop cost reports. The application of IoT technology in construction enables efficient and prompt inspection and reporting of information in real-time, surpassing traditional methods (Nagy et al., 2018). This creates opportunities for monitoring and reporting construction expenses, which is a crucial aspect of construction cost control in real-time.

By incorporating IoT technology into the construction industry, stakeholders can benefit from enhanced data collection, analysis, and reporting capabilities. Real-time monitoring and reporting of construction costs facilitate proactive decision-making, allowing for timely cost control measures and adjustments. The integration of IoT technology empowers construction professionals to streamline cost management processes, optimize resource allocation, and achieve more efficient and effective cost control throughout the project lifecycle.

5.3 Big Data (BD)

Notwithstanding the lack of consensus over its precise definition is, BD can be defined as "a collection of data sets so huge and complicated that it becomes challenging to process using the available database management technologies" (Lu et al., 2018). Big data refers to the platform for collecting massive amounts of high volume of project data, in diverse array, and/or high-velocity contained within various formats as well as file type (Han & Golparvar-Fard, 2017). The construction industry, especially in terms of cost management, is naturally "data-rich." There is a constant generation of cost management data from various projects over their lifecycle, including bidding documents, bills of quantities, engineering and architectural drawings, master production schedules, schedules of rates, labour rates, repair and maintenance schedules process/routing sheets, accounting records, catalogue and supplier information, and standard time data (Lu et al., 2018)

Consequently, BD represents a valuable yet often overlooked asset that has the potential to significantly enhance quantity surveying (QS) business and address challenges associated with the profession. BD can help overcome issues such as error-prone and time-consuming measurements, time constraints, and imprecise estimates in QS service delivery. By harnessing BD, the construction cost control process can be improved, ensuring that the final construction cost aligns with the client's approved budget.

The utilization of BD in construction cost control enables more accurate and efficient data analysis, leading to better decision-making and cost management strategies. By leveraging BD, QS professionals can access a wealth of information that can inform cost estimation, project scheduling, resource allocation, and risk management. This ultimately contributes to enhancing the overall effectiveness of construction cost control and helps maintain budgetary adherence throughout the construction process.

5.4 Building Information Modelling (BIM)

BIM is currently a fundamental subject for the advancement of the construction industry and supporting the concept of the 4IR in the construction industry (Oesterreich & Teuteberg, 2016). By incorporating various features, BIM can provide an accurate representation of a project's components (Abdullahi et al., 2019; You & Feng, 2020), a comprehensive three-dimensional model can be employed to provide a complete description of the buildings' definition information (Soust-Verdaguer et al., 2017). BIM dimensions refer to several subsets of BIM, 3D represents the object model, 4D represents time, 5D represents cost, 6D represents operation, 7D represents sustainability, and 8D represents safety (Smith, 2016).

However, one of the primary challenges in cost control is receiving accurate and timely feedback from construction sites, managing various types of information, and analysing the data to create cost reports (Lu et al., 2018). An as-built BIM can help with compiling reports accurately and in a timely manner by connecting to the as-built design, schedule, and cost. Essentially, an as-built BIM is an information model that is synced with the construction process in real-time, allowing for reliable information exchange and informed decision-making, according to Chen et al. (2015).

The integration of modern technologies, such as laser scanners, sensors, and cameras, further enhances the capabilities of as-built BIM. These technologies enable real-time data collection from the construction site, facilitating automatic or semi-automatic updates to the as-built BIM model (Boroujeni & Han, 2017). By comparing the as-built BIM model to the as-designed BIM model, discrepancies can be identified and addressed. The utilization of as-built BIM empowers Quantity Surveyors to track the construction process and deviations effectively. It automates monthly cost reporting, improves visual representation, and ensures traceability. This integration of real-time data and accurate feedback from the construction site enables Quantity Surveyors to take timely and appropriate actions to control total costs.

In summary, BIM, particularly the utilization of as-built BIM, plays a vital role in construction cost control by enabling accurate and timely feedback from the construction site, streamlining data management, and facilitating informed decision-making. The integration of BIM with modern technologies enhances its capabilities and provides valuable insights for effective cost control throughout the construction process. Meanwhile, BIM-based software will compare the as-built BIM model to the as-designed BIM model to discover discrepancies. BIM should aid in the integration of fast and accurate feedback from building sites and enable Quantity Surveyors to take remedial actions to control total costs (Lu et al., 2018). As-built BIM can assist in tracking the construction process and deviations, allowing for the automation of monthly cost reporting and the settlement of interim payments with improved visualisation and traceability (Lu et al., 2018).

6. Conclusions

This paper conducted a comprehensive literature review to explore and evaluate construction cost control methods, techniques, and tools while incorporating key drivers from Construction 4.0. The findings highlight the significance of addressing cost overruns in construction projects, which are commonly encountered during the construction phase. The review emphasized the importance of precise, time-based cost information and accurate periodic construction cost data to achieve effective cost control. Furthermore, the study identified CPS/DT, BIM, IoT, and BD as prominent drivers of Construction 4.0, showcasing their potential in enhancing construction cost control practices. By leveraging Construction 4.0 technologies, such as CPS/DT, BIM, IoT, and BD, construction professionals can benefit from advanced analytics, real-time monitoring, and improved decision-making processes. These technologies provide valuable insights into time- and cost-sensitive project areas, enabling proactive measures for effective cost control throughout the construction lifecycle. Integrating CPS/DT facilitates the seamless interaction between physical and virtual systems, enhancing project monitoring and reducing errors. BIM enables accurate as-built models, aiding in tracking construction progress and discrepancies. IoT allows for efficient data collection, while BD manages vast amounts of diverse construction data.

The utilization of Construction 4.0 technologies in construction cost control offers significant advantages compared to traditional methods. These technologies empower construction firms to optimize their cost control strategies, ensuring that the approved budget aligns with the final construction cost. The findings of this study emphasize the need for construction industry stakeholders to embrace Construction 4.0 principles and leverage the available technologies to achieve safer, more environmentally friendly, and efficient construction projects. By adopting a holistic approach that integrates Construction 4.0 drivers into construction cost control practices, industry professionals can overcome challenges associated with cost overruns and enhance project outcomes. Policymakers, industry stakeholders, and construction firms can utilize the insights from this research to develop targeted strategies and interventions that effectively address cost control challenges in the 21st century, particularly in the context of the Industry 4.0 era. It is crucial to embrace innovation and leverage technology to ensure the successful implementation of robust cost control measures and achieve sustainable construction practices in the ever-evolving construction industry.

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