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Digital technologies and data-driven delay management process for construction projects

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One of the main challenges of construction projects is managing delays; there is still a lot to overcome to reach near-zero delays (mitigation of delays) in all construction projects. Technology and different platforms are applied to support a high volume of data flow acquired from multiple resources during the construction project life cycle; how can these automated and digital progress tracking systems be considered for more effective construction delay management? The aim is to investigate the current state of real-time technologies and their applications and assess how specific attributes of these disruptive technologies can significantly alter delay management in construction industries. Therefore, this study presents a new process-based framework for using technologies with a data lifecycle viewpoint. This research uses a four-step systematic literature review involving identification, screening, extortion-eligibility check, and selection-inclusion. Furthermore, it is followed up by a thematic content analysis on using new technologies to mitigate delays in construction projects. Key trends, themes, areas of concern for research, and limitations identified in previous literature as research gaps and future needs were documented and structured. This work presents a novel process of comprehensive classification of real-time technologies that are being used in the construction industry to acquire data, screen/analyses data, and present information through an Industry 4.0 application: IoT technologies such as sensors, RFID *etc.*, smartphones, planning/scheduling tools (Ms Project, Primavera), and Building Information Modelling (BIM). The developed process-based framework is served as a roadmap to 1) centralise real-time communication between technologies to collect, analysis and presentation data in construction phase, 2) prepare timely reports for project managers to take proper action against those problems delaying project.

KEYWORDS

mega and smart construction, data acquisition, progress tracking, industry 4.0, delay management, real-time

1 Introduction

Delay is still one of the key challenges of construction projects. Construction projects are trialing different technologies to reach near-zero delay in all project life cycles; therefore, technologies have a significant role in improving productivity and reducing project timeframes as much as possible. Delays can lead to negative impacts such as broken communication among stakeholders (client, contractors), contract termination, low productivity and loss of revenue (Sepasgozar et al., 2015). Construction projects have complex and dynamic site jobs with many activities and resources, including software (workforce) and hardware (plant, equipment, and materials). Between 2006 and 2021, some statistical reports presented that cost overruns and schedule delays are common problems, frequently leading to disputes and costly claims in construction project delivery (Perttula et al., 2006; Pinto et al., 2011; Li et al., 2016; Soltanmohammadlou et al., 2019; Shirowzhan et al., 2020; Brusselaers et al., 2021). In contrast, although construction projects use digital/real-time technologies, construction sites still experience many delays (Li et al., 2016; Gunduz and Laitinen, 2018; Bakeli and Hafidi, 2020).

Moreover, access to real-time project progress status reports is one of the key concerns for construction project decision-makers (Gunduz and Laitinen, 2018; Getuli et al., 2020). Radman et al. (2021) have presented an analytical study to prioritise key factors causing delay and impacting timely decisions regardless of using progress tracking systems in smart construction projects. In terms of "smart" terms in construction projects, a widely accepted definition of "smart construction" is: a building design, construction and operation that, through collaborative partnerships, makes full use of digital technologies and industrialised manufacturing techniques to improve productivity, minimise whole life cost, improve sustainability and maximise user benefits (Construction Leadership Council 2018; Bucchiarone et al., 2019; Radman et al., 2021).

Substantial research has been carried out on automated technologies in construction projects, such as 1) the use of remote sensing technologies from 2D photo-feature extraction to 3D laser scanners; 2) Radio Frequency Identification (RFID) tags for automated data acquisition in construction job sites; 3) Ultra-wideband (UWB) for data detecting, acquiring, and monitoring; and 4) access to real-time data Industry 4.0 focuses on digital technologies with the help of interconnectivity through using the Internet of Things (IoT) applications/technologies in the supply chain, safety, and project management concepts (Li et al., 2016; Asadi et al., 2018; Al-Saeed et al., 2019; Ghosh et al., 2020). Karmakar and Delhi 2021 have summarised the knowledge advancement of construction 4.0 to present technologies, and process conceptualisation which is nowadays associated with Industry 4.0 reverberate in construction 4.0 (Karmakar and Delhi, 2021). However, IoT-based sensors and technologies often lead to the generation of large datasets captured through construction scheduling, tracking, localisation, and 4D/5D-BIM in construction projects (Benjaoran and Bhokha, 2010; Omar and Nehdi, 2016; Karmakar and Delhi, 2021). From a scheduling point of view, automated technologies mitigate the potential negative impact of schedule delays and cost overruns, but they can also help improve safety and productivity on site (Cheng et al., 2017; Fujisaki, 2019; Yoshigai and Fujisaki, 2020). While the previous reviews present technologies for data collection and progress tracking systems, some concepts, such as management systems and automated and integrated management system applications, have received limited attention (Feng and Golparvar-Fard, 2019; Moselhi et al., 2020). For instance, Kazemian (2019)bib_kazemian_et_al_2019bib_kazemian_et_al_2019 tried to present an efficient integrated management application, but it did not cover timely delay reports, disruption, clashes, productivity, and percentage completion from the site (Kazemian et al., 2019). In 2020, a comprehensive review of the digital twin concept was done by Sacks et al. (2020). They offered digital twin construction to manage production in construction by leveraging data streaming from various Industry 4.0 ideas. It was for site monitoring to accurately yield information status and proactively analyse ongoing design, planning, and production. However, some gaps have remained in their research: designing a suitable data storage mechanism, making each part of the system compatible with AI functions, decreasing the interpretation of multiple data streams during the project; and considering a commercial model (Sacks et al., 2020). However, despite significant work, some gaps can be recognised in Sacks' research. For example, a proposed workflow to support project stakeholders to proceed with the decision-making process faster is not clearly mentioned.

While each of the mentioned research streams has provided a wealth of knowledge, these areas of expertise are significantly fragmented and unconnected. Some studies have focused on the particular role of automated management systems in analysing delays caused by the location of workers, storage, equipment, and materials (Golparvar-Fard et al., 2009; Shahi et al., 2012; Guo et al., 2017; Kropp et al., 2018; Bortolini et al., 2019; Kazemian et al., 2019; Sheikhkhoshkar et al., 2019). Furthermore, using automated project tracking systems such as expanding from single sensory analysis to multi-sensory, activity-based-data-fusion models and objective-based-data-fusion models (Li and Becerik-Gerber, 2011; Choe et al., 2014; Shahi et al., 2015; Omar and Nehdi, 2016; Choe and Leite, 2017; Hamledari et al., 2017; Labant et al., 2017; Kanan et al., 2018). Generally, through the knowledge gained from literature, "delay management" is set of techniques such as Revised-Schedule, As-Planned and As-Built to measure projects performance from time, cost and scope perspectives (Indhu and Ajai, 2014).

Apart from the above, in light of delay management, Radman et al. (2021) analytically presented a statistical relation during construction life cycle phases between 1) technologies that have been used; and 2) key project participants such as clients, consultants, sub-contractors, and 3) those possible causes of delay factors such as material, workforce, equipment/tools, changes/variations, financing/funding, contractual relations and environment/government actions. Their study identified that regardless of using technologies to mitigate or monitor those delay factors caused/by caused projects, there is still rarely a comprehensive process to integrate technologies for managing delays, especially in real-time purpose. Therefore, there is a need to identify the process(s) of state-of-the-art real-time data acquisition systems and fusion methodologies applicable for delay mitigation in construction projects and their associated challenges. Therefore, this study contributes to providing construction project decision-makers with a deeper and richer understanding of the relationship between automated/real-time technologies and their role in each phase of project data flow (e.g., data collection, data screening, data fusing, data visualisation), to facilitate the application and integrated utilisation of these technologies. As a result, current research presents a novel process-based perspective using technologies through the data processing lifecycle that can prevent or mitigate site work delay(s) in construction projects. The study aims to provide a delay prevention roadmap by recommending and structuring fit-for-purpose technologies in the right situation and time. Accordingly, this work has highlighted the growing interest in reviewed literature through three classes and four key study streams:

- Three classified classes: (1) data collection, (2) data screen and (3) data analysis.
- Four study streams: 1) Identifying relevant trends of digital technologies across different thematic areas; 2) classifying the range of automated technologies in construction focusing on productivity/delay management; 3) classifying pros and cons according to real-time progress tracking and data management technologies to support delay management; and 4) proposing a process-based framework of using digital technologies regarding delay management in the construction industry.

2 Research methodology

Through the systematic literature review, a significant amount of data can be holistically collected, assessed, synthesised, and converted into theoretical findings, specific gaps and requirements of the knowledge areas (Agudelo et al., 2019; Fink, 2019; Shafiee et al., 2019). A more detailed investigation of study subjects through a review of previous works enables the extraction of novel and new ideas (Kupiainen and Jansson, 2017; Kong et al., 2018). To perform an effective systematic review, four common steps suggested by Denyer et al. (Tranfield et al., 2003; Denyer and Tranfield, 2009; Briner and Denyer, 2012) as well as other authors have adopted a feature of the PRISMA statement (Moher et al., 2009; Page et al., 2021):

- Step one, identification: identify the main keywords and context based on the research objectives.
- Step two, screening: find relative publications based on the keyword identified in step one.
- Step three, extraction/eligibility: develop selection criteria for screening publications and identify the most relevant and critical publications.
- Step four, selection/inclusion: report the results of the review.

Figure 1 demonstrates a breakdown of the research strategy flowchart based on the four-step methodology: identify the need for the review; screen (based on title and abstract); extract (comprehensive, accessible research); and select (report the results).

Several electronic databases were chosen to find the related publications/presentations: Scopus, Discover, Google Scholar, Web of Science, Elsevier, Taylor and Francis, Emerald, Springer, and American Society of Civil Engineers. To address our primary research, through four steps (Figure 1) objectives and articles were searched by title, abstract, or keywords during the last 10 years to specify how eligible and relevant they were. The research strings for utilising introductory browsing are demonstrated according to the main subject under review. Hence, all scholarly papers that address strings were highlighted (Table 1). Due to the availability of a large amount of literature related to this study, Figure 1– step 3 (full-text articles) was defined as an eligibility criterion to evaluate independently by the authors based on a set of defined inclusion and exclusion criteria such as relevant date, language, document type limitation and subject areas (Table 2). Moreover, regardless there is three phases in construction project: pre-construction, construction and post-construction, the current articles considered to identify type of technologies/tools have been using/used into construction phase to data stages such as data collection (DC), data analysis (DA) and data presentation (DP). Therefore, this research filtered the articles only focusing on the construction phase and in data stages purposes.

Post this stage, all potentially relevant articles were filtered by themes while those studies that fulfil the following criteria alongside the delay concept in the construction industry:

- focus on the progress tracking of construction projects
- focus on data management and
- focus on technology in construction management.

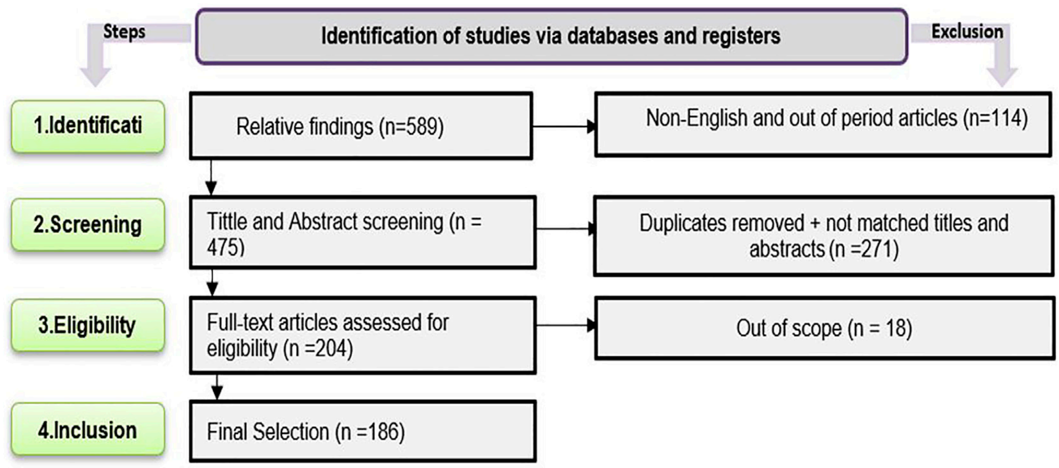

FIGURE 1
Search strategy flowchart.

TABLE 1 Research strategy- strings.

Theme	Search strings	Boolean operator
Construction progress tracking	real-timeˆ OR progress trackingˆ OR construction management systemsˆ OR smart constructionˆ OR automatˆ OR delay managementˆ OR productivity	AND
Data management	Integrated management systemsˆ OR data collectionˆ OR analysed dataˆ OR DBMS	AND
Digital technologies in construction productivity management	IoT technologiesˆ OR delay analysisˆ OR sensory progress trackingˆ OR non-sensory progress trackingˆ OR technology	—

TABLE 2 Research selection criteria: Inclusion and exclusion.

Research selection criteria	Research inclusion	Research exclusion
Relevant dates and topics	Period: 2010 to 2022 Single and multiple sensory progress monitoring, automated systems in construction, delay management, productivity, smart construction project, Wireless Sensor networks, digital applications, Object detection, Activity detection, Tacking systems, delay in construction, Industry 4.0	Out of period, type of technologies related to underground services and machinery
Document type	Research articles containing literature Review, conceptual framework, case study (experimental, analytical, and modelling studies), thesis	Reports, conference papers
Language	Full accessible studies in English	Non-English
Subject areas	Construction: site, project, industry	Post and pre-construction phases of building lifecycle; studies referring to ONLY technologies in construction projects alone

The selected keywords were classified into three themes for searching articles. The themes and selection of keywords are demonstrated in Table 1.

Accordingly, all articles and documents meeting the inclusion criteria were selected for this study (Figure 1 - step 4). Furthermore, it included peer-reviewed journal articles and all of the scholarly literature that addressed real-time, delay, automated, progress tracking, Industry 4.0 (IoT-based technologies) such as RFID, Global Positioning System (GPS), Ultra-Wideband (UWB), data acquisition and fusion, and/or their relevant terms in the field of construction job sites. Furthermore, a close examination of the articles and publications was conducted to identify and finalise the most relevant research area.

3 Findings and results

According to the steps defined in Figure 1, between 2010 and 2022, the total number of annually published studies on the current study topic is 589. Also, after applying the eligibility assessment (Figure 1 - step 3), 186 published articles were initially identified. The descriptive analysis was broken down into two aims as follows: 1) demonstrate insights according to current work trends in real-time technologies of collecting and presenting data in the construction industry for delay management purpose (Section 3.1- Figure 2 and Figure 3); 2) demonstrate those stand-alone and combined real-time technologies have been using either directly (active dada) or indirectly (passive data) for data acquiring and/or data presenting about delay management (Section 3.2-Table 3). General speaking, "active data" is automatically managed because it is actively provided by user, while "passive data" collected without requesting from user and needs to be managed manually or sometimes semi-automatic (Dal Moro et al., 2015). However, Figure 4 also illustrates the distribution of those technologies have been using/used for data stage: data acquiring (DC), data analysis (DA) and data presentation (DP) in delay management purpose.

3.1 Publications based on date and themes

The findings are structured in a brief description of publication sources, journals, research methods and smart technologies. Figure 2 summarises the 186 published studies on construction management topics from 2010 to 2022 (quarter 2). Overall, the outcome shows a growing research interest since 2014 over the studied time span, especially after 2018. Approximately 52% of the studies are from 2018 onwards.

Figure 3 shows that publications with themes "Construction Progress Tracking" and "Technology in construction productivity management" have around 69% of the considered literature released in the time span (129 published out of 186). In contrast, "Data management" is the next place in construction, with 57 articles (about 31%). This reveals a wide range of technologies for data acquisition/tracking within construction sites while managing data for specific purposes such as delay management, earned value management and smart progress tracking platforms is still growing.

3.2 Publications based on type of technologies

Table 3 illustrates different research approaches that have been used for delay management purposes; those can be classified into two major groups and split into tools/technologies and data stage (DC, DA, DP) distributed from 2010 until 2022 (second quarter). Moreover, Table 4 shows how technologies have been distributed among data stages. Based on this report, regardless 60% growth of using tools only for DC or DC/DA, demand of using tools regarding the whole data stage (DC/DA/DP) is significant, 40%. Meanwhile, it declares that desirability of using tools for whole data stage depends on type of tools and how would be compatible with others. For instance, BIM in stand-alone side and BIM and other applications in combination side are of about 27% popularity out of 40% in total of whole data stage, while demand of using RFID/WSN against stand-alone RFID is 2%–7%. In other words, even if popularity of the combined tools is increasing but features and capabilities are not growing straightforward.

As seen in Tables 5, 6, the first group includes 114 studies (61%) focused on stand-alone technologies and tools, which can vary depending on the data type (e.g., text, photo, number, drawing), data accuracy and the environmental situation in data acquiring. Primarily, this group provided a framework, model, and case study for approach(s) verification through site experiments or lab simulations. In details, Table 5 demonstrates that between 2010 and 2022 about 33% of stand-alone tools such as sensors, RFID and laser scanning have been used for data collection (DC) while only 19% attention on mixed stage (DC/DA/DP). However, it shows 9% of stand-alone tools have been used for DC/DA.

The second group consists of 72 articles with a focus on combined technologies regarding data acquisition and tracking systems including DC/DA/DP. These articles have applied a hybrid method of tools development or case study for the survey. In general, the trend analysis indicates that the research trend in this topic is significantly chasing promising real-time construction project management approaches through developing novel and prototype tools and processes. Table 6 illustrates 40 out of 72 studies have presented technologies such as BIM/other applications and Planning software have been used all data stages (DC/DA/DP) as a package.

Moreover, 46 articles validated their proposal using tools and technologies to collect data (DC) in the construction industry through case-study on construction sites such as commercial buildings, road projects, or civil projects. However, material tracking systems use RFID Devices and Barcodes (QR) to identify materials in the supply chain management cycle (Tezel and Aziz, 2017; Han et al., 2018; Álvares and Costa, 2018). In DC/DA category, vision-based technologies such as photogrammetry or videogrammetry and laser scanning were used to automate progress reporting and make 3D models in the construction industry (Cho et al., 2018). Augmented Reality (AR) is known as live, computer-generated imagery and physical view (direct or indirect) to augment the real-world environment in virtual elements. However, some key practical challenges of AR mobility still need to be considered, such as less user-friendly,

FIGURE 2
A number of publications Vs. published years.

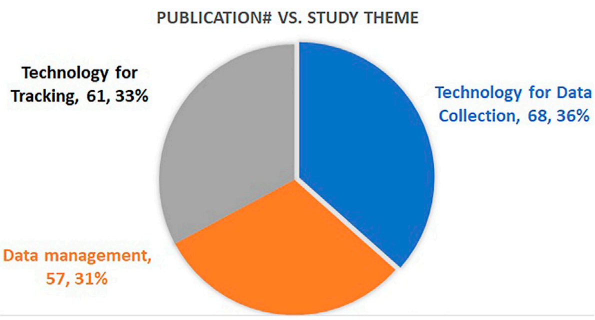

FIGURE 3
A number of publications Vs. Study Theme.

power concerns, ability to function in harsh environments, uncontrolled conditions for robust image registration and noise filtering (Wang et al., 2004) (Park et al., 2017). Furthermore, BIM tools such as Revit, ArchiCAD, Navisworks and BIM360 can be used as data acquisition (DC), data analysis (DA) and are very powerful supportive features for smart information systems in managing delays into construction projects (DP). For instance, BIM360 is a cloud-based app to collaborate and report information such as marked-up drawings, modified drawings, and record modifications to manage real-time data from a cost viewpoint (Wang et al., 2004; Eliwa et al., 2022).

In contrast, construction progress monitoring is supported by a variety of tools and technologies to alarm delays such as 1) project management tools (e.g., Primavera, Ms project, Team

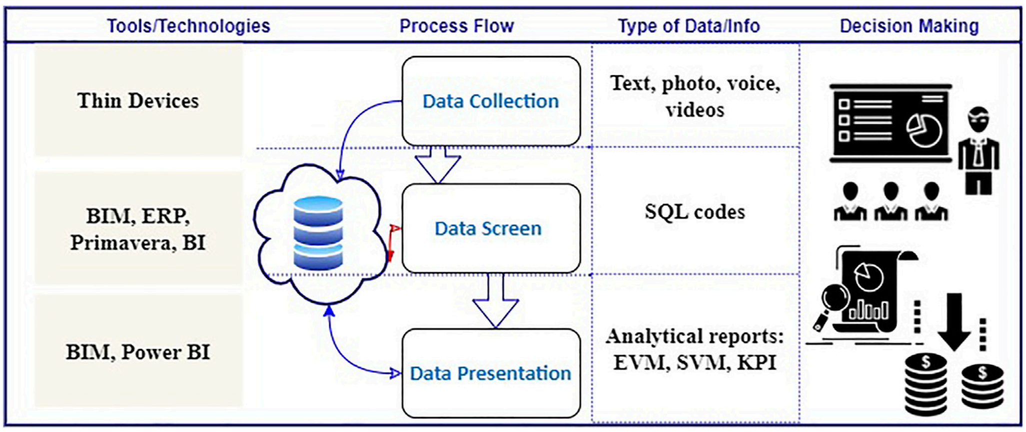

FIGURE 4
The proposed framework.

TABLE 3 Publication distribution by research method and technologies.

Method / year	Standalone Technologies/Tools												Combined Technologies/Tools									
	Barcode	GPS, Bluetooth	Infrared	Laser scanning	Photo/Videogrammetry	RFID	Robotic total station	UWB	BIM	Smart Device	Sensore	Planning Software (PS)***	GPS + Barcode	GPS + RFID	Laser scanning + UWB	Photo/videogrammetry + UWB	Photogrammetry + laser scanning	Photogrammetry+ RTS station	RFID + Laser Scanning	RFID + WSN	BIM + other applications****	Sensores + othe applications
Total	114												72									
2010	2	1		2	2	1			1	1	1	1	1				2				1	1
2011	1				1	2		1	1		1	1			1		1				2	2
2012				2	1	2	1	1		2	2	1		1	1		1	1	1		1	1
2013		1			2	2	1		1			1	1	2				1		2		
2014		2		1		2		3	2		2			1	1						2	2
2015			1			1		1	3	1	2	1		2					1	1	2	2
2016					1	1		1	2	1		2		1							3	1
2017		1		2		1			3		2		1				1				2	1
2018		2			1	1			2	3	1									1	2	2
2019				1	1				2		2	1				1			1		2	
2020									3	2	1				1				1		2	2
2021									3	1	1	1					1		1		2	
*2022									3		3										3	2
**Stage	DC	DC	DC	DC/DA	DC/DA	DC	DC	DC	DC/DA/DP	DC	DC	DC/DA/DP	DC/DA	DC/DA	DC/DA	DC/DA	DC/DA	DC/DA	DC/DA	DC/DA	DC/DA/DP	DC/DA/DP

*2st Quarter
*** Primavera, Ms Project
**DC: data acquiring & DA: data analysis & DP: data presentation
****other applications: RFID, AR, PS

planner) to monitor progress, track status and delays through the project; 2) 4D-BIM (integration of scheduling tools like primavera/MS Project and BIM) to collect data, analysis and present them; 3) photogrammetric 3D mapping such as using Unmanned Arial System imagery and performance indicators; 4) a combination of schedule tools with 3D sensing technologies and 4D CAD modelling to cover gap of data collection and analysis (Turkan et al., 2012; Kim et al., 2013a; Eliwa et al., 2018) and using sensors to optimise resource tracking by applying electromagnetic stimulation (Cho et al., 2018). In DC/DA stage, some hybrid-tracking systems integrate BIM, Bluetooth Low Energy (BLE) technology and motion sensors to acquire location awareness of assets (Park et al., 2017). In regards to a vehicle tracking system, Wang et al. (2004) used three ultrasonic sensors alongside a laser radar integrated with the CAN bus. A Controller Area Network is a robust vehicle bus standard designed to apply microcontrollers and devices to communicate with each other's applications without having host computers which can be listed in DC/DA stage.

They used CAN bus to build the in-vehicle network architecture to illustrate different directions to the driver. Around 2011 an algorithm was presented and utilised for real-time safety management in construction sites (Carbonari et al., 2011). Accordingly, key Industry 4.0 technologies (Turner

TABLE 4 Technologies distribution among data stages.

Data stage/Technology	"Total"	%
DC	62	33%
Barcode	3	2%
GPS, bluetooth	7	4%
Infrared	1	1%
RFID	13	7%
Robotic total station	2	1%
Sensor	18	10%
Smart Device	11	6%
UWB	7	4%
DC/DA	**49**	**26%**
GPS + Barcode	3	2%
GPS + RFID	7	4%
Laser scanning	8	4%
Laser scanning + UWB	4	2%
Photo/Videogrammetry	9	5%
Photo/Videogrammetry + UWB	1	1%
Photogrammetry + laser scanning	6	3%
Photogrammetry + RTS station	2	1%
RFID + Laser Scanning	5	3%
RFID + WSN	4	2%
DC/DA/DP	**75**	**40%**
BIM	26	14%
Sensors + other applications	16	9%
Planning software (PS)	9	5%
BIM + other applications	24	13%
Grand total	**186**	**100%**

TABLE 5 Distribution of data stages in stand-alone technologies.

Stand-alone	"Total"	%
DC	62	33%
DC/DA	17	9%
DC/DA/DP	35	19%
Grand total	**114**	**61%**

TABLE 6 Distribution of data stages in combined technologies.

Combined	"Total"	%
DC/DA	32	17%
DC/DA/DP	40	22%
Grand total	**72**	**39%**

et al., 2020) such as IoT devices (e.g., smartphones, sensors, robots and cameras), artificial intelligence, cloud, fog and edge computing technologies offer new opportunities to provide the essential dependability to time-critical smart construction projects such as construction site management (e.g., process tracking, workers' locations, BIM) and construction monitoring (e.g., quantitative status, trades positions, terrain reconstruction). Some challenges still exist and need to be addressed, such as the application of fast application performance vs. requirements for low-cost operations; or fusing data requirements vs. data privacy requirements (Zambrano et al., 2014; Štefanič and Stankovski, 2018). Therefore, Irizarry et al. (2013) presented how digital technologies such as BIM, GIS, GPS, UWB, RFID, AR/VR, and LADAR imaging have been used in real-time data acquisition. They focused on integrating BIM and GIS, which are used to improve the construction visual monitoring regarding supply chain management. GIS technology may deliver location information that can eliminate site workers' intensive data collection and labour costs and reduce data entry errors (Irizarry et al., 2013).

Nowadays, smartphones come with modern sensors, onboard storage, computing processes and communication facilities. Smartphone-driven monitoring systems have been used in healthcare systems (Mahmud et al., 2017); localisation solutions for construction site management (De Dominicis et al., 2013; Enck et al., 2014); vehicle tracking systems (Lee et al., 2014); unsupervised construction of an indoor floor plan (Shin et al., 2011) and remote indoor construction progress monitoring (Khairadeen Ali et al., 2021). While dozens of studies focus on modern smartphone features (e.g., sensors) and applications (such as live chat, email, photo, and video) through instruments with a variety of sensing modules, several of the existing studies merely utilise the data acquiring (methods and process) by smartphone technologies. Moreover, smartphones can drive timely decision processes faster for project managers in smart construction projects (Villalba et al., 2017; Alavi and Buttlar, 2019).

Through previous literature reviews, Li et al. (2017), Oraee et al. (2017), and Wang et al. (2014) have presented a similar concept of "location systems" but in different situations for DC/DA purposes; for example:

- Real-time location systems are based on the Time-Of-Arrival functionality, such as GPS, Ultra-Wideband (UWB), and Robotic Total Station.
- People and object tracking and localisation systems use Wi-Fi-/Bluetooth technologies to measure occupancy.
- Location estimation systems use location and behavioural algorithms through smart devices (phone and watch) and Bluetooth headsets to track the changes in the received electromagnetic waves related to the number of people or vehicles on site.

Some articles have generally involved more than one type of tool or utilised a combination. 40 papers out of 72 (56% of combined technologies/tools) have applied a variety of BIM or

TABLE 7 Data stages distribution between combined and stand-alone technologies.

Combined	"Total"	%
DC/DA	32	17%
DC/DA/DP	40	22%
Grand total	72	39%
Stand-alone	"Total"	%
DC/DA	17	9%
DC/DA/DP	35	19%
Grand total	52	28%

sensors with other applications/technologies such as 1) Industry 4.0 (IoT, robotics, artificial intelligence, BIM, automation, digital twin, sensors, and wearables); 2) RFID; 3) Augmented Reality (AR), and 4) planning software (Primavera and Ms project). For effective delay management (site productivity), timely availability of accurate data is essential. Project stakeholders, especially project managers, would be able to make timely decisions to manage delays and disruptions in the project (Omar and Nehdi, 2016; Ramachandran and Perumal, 2018). For instance, one of the most encountered methods related to construction delay claims is a comparison of "As-Planned" vs. "As-Built" events and data. This method simply can compare what was supposed to happen to what happened. Therefore, "data" power and role must be significantly considered (Atanasov et al., 2020; El-Samadony et al., 2020; Türkakın et al., 2020). In contrast, it is worth noting that the real-time data tracking approach is categorised as part of automation topics in the construction industry. It has been increasingly investigated in the last decade (Li and Becerik-Gerber, 2011; Kropp et al., 2018). Furthermore, Turner et al. (2020) addressed a comprehensive review of Industry 4.0 technologies adopted within the construction industry. While the complexity of construction projects is increasing, it illustrates how industrial connectivity tries to ensure all Industry 4.0 technologies keep interconnecting for higher productivity within the construction industry. In DC/DA/DP stages, Chowdhury et al. (2019) reviewed the vital benefits and barriers of digital technologies being used in New Zealand to improve construction industry productivity, focusing on cost reduction engineering and Ubiquitous Digital Access.

4 Discussion

As illustrated, previous literature has focused on obtaining data from construction sites *via* digital technologies to track site progress, people, locations and productivity. In contrast, these data and analysis should be used for delay analysis (Radman et al., 2022). However, these studies have different views of the role of data in construction delay management, and there is no streamlined data collection (DC) process for this data analysis/presentation (DA and DP) cycle. However, Table 7 illustrates regardless about half of publications (Table 3: 72 *Vs*. 114) presented using combined technologies/tools through data stages, less than a decade there is 11% growth in using the combined technologies encouraged this research to focus on an integrated process of using combined compatible technologies/tools in data stages' purpose. As a supportive evidence, Table 8 and Table 9 listed the key advantages and disadvantages of single and combined digital technologies have been used/using for DC, DA and DP into construction phase.

Accordingly, based on finding gaps through the literature reviews, Section 5 will propose a process-based framework to show how an integrated process of data collection to data presentation will be organised by using compatible technologies/tools to increase productivity and early delay alarm for stakeholders. It facilitates decision making, manages data obtained and mitigates possible delays in a timely and effective manner. Therefore, before demonstrating the proposed framework in detail, some of those technologies can be used and patterned an integrated process of using technologies through data stages have been identified. For these particular purposes, the current study has divided technologies into combination of data collection (DC), data analysis (DA) and data presentation (DP) as follow:

4.1 Data collection

The general form of communication is defined as "Media," which comprises documents, audio, and videos. In real-time, smart industries are progressively interested in coping with media communication as an easier and faster way to collect data (Omar and Nehdi, 2016). Literature shows that since 2010, digital communication channels such as audio recordings, low pixel digital photographs and low-size videos have been used to analyse construction industry delays. The project team usually attach them as a support document to activities scheduled through the construction programme (Abdelrehim, 2013; Omar and Nehdi, 2016). From the visualisation point of view, multimedia is very popular and desirable due to its capability to highlight problems understandably (Hegazy et al., 2008; Omar and Nehdi, 2017; Kamarah, 2019). Another way to collect information is smartphone features such as QR code scanning and many other applications capable of construction site teams entering where they have started and finished assigned tasks with low maintenance requirements and infrastructure costs (Mohagheghi-Fard, 2019; Zhao et al., 2019; Babaeian Jelodar and Shu, 2021). Moreover, email communication is an official channel to

TABLE 8 Key advantages and disadvantages: single digital technologies.

Technology	Advantages	Disadvantages
RFID	• Light tags	• Limited coverage
	• Batch readability of tags	• For active tags, battery replacement is required.
	• Data acquisition effort	• 3% lack of accuracy
	• Affordable	• Passive data
		• Not reliable
		• Lack of compatibility with other digital tools
Reference	Rashid and Louis, (2019); El-Omari and Moselhi, (2011); Bae and Han, (2019); Pătrăucean et al., (2015); Kim, Son, and Kim, (2013); Turkan et al., (2012)	
WSN	• Offers good radio coverage	• Low positioning accuracy (2.5%) due to high noise
	• Data acquisition effort	• Not affordable
		• Not reliable
		• Lack of processing time
Reference	Subedi et al. (2017); Maneesilp et al. (2012); Moretti et al. (2019); Valero and Adán, (2016); Elghaish et al., (2019)	
LS	• Compatible with: CAD, BIM, Point cloud data	• Do not address the need for modelling all available objects
	• Affordable	• Room to be as empty as possible when scanned
		• Less accuracy (around 4.6%)
Reference	Moselhi et al. (2020); Raza (2017); Baronti et al. (2018); Mendoza-Silva Torres-Sospedra and Huerta (2019); Ruiz and Granja (2017); Abdelhafiz and Mostafa (2020); Julin et al. (2019); Alshawabkeh (2006); Hamledari et al. (2017); Shahi et al. (2012)	
UWB	• Large bandwidth,	• not reach 100% of coverage for the area tested
	• High accuracy	• line-of-sight technical issues
	• Low power consumption	• Not affordable
		• Lack of compatibility with other digital tools
Reference	Shahi et al., (2012); Aryan et al., 2021; Golparvar-Fard et al., (2011); Chen et al., (2019); Park, Cho, and Martinez (2016)	
PVG	• Easy interpretation,	• 2% error in volumetric measurement
	• High Probability,	• Objects' configuration error with unclear geometric
	• Recognisable objects colour,	• Less accurate (~2%) than laser scanners
	• Suitable references for inspection	• Lack of scalability
		• Not affordable
		• Less compatibility with other digital tools
Reference	Moussa and Fritsch, (2010); Akmalia et al. (2014); Julin et al. (2019); Liu and Kang (2014); Brunetaud et al. (2012); Zhang and Lin (2017); Moselhi et al. (2020); Arslan et al. (2019); Feng and Golparvar-Fard (2019); Shahi et al. (2012)	
BIM	• Cloud-based	• Not automatic links between progress reports and the planned schedule
	• Record daily reports	• Expensive (licence based)
	• Track daily Ready for Information (RFIs)	• Need skilled and experienced people
	• High compatibility with other digital tools	• Access Internet for cloud-base version
	• Marked up drawings are attached	• Marked up drawings are not linked to related activities.
		• Expensive and Reliable results
Reference	Hamledari et al., (2017); Kropp et al., (2018); Mirzaei et al., (2018); Bortolini et al., (2019); Sheikhkhoshkar et al., (2019)	

(Continued on following page)

TABLE 8 (*Continued*) Key advantages and disadvantages: single digital technologies.

Technology	Advantages	Disadvantages
PMST	• Popular to use	• Expensive (licence based)
	• Match Ms Office (e.g. Excel)	• Need killed and experienced people
	• Cloud-based	• Access Internet for cloud-base version
	• Track progress and EVM	• Different engines different software compatibility
	• Medium compatibility with other digital tools	• Expensive and Reliable results
Reference	Kakde and Desai, (2017); Romigh et al., (2017); Ando et al., (2020); Asri and Susetyo, (2020); Vanhanen, (2021)	

TABLE 9 Key advantages and disadvantages: combined digital technologies.

Technology	Advantages	Disadvantages	References
Real-Time Communication Channels	Review questions and answers; Attach media and documents; Visual data recording; Quick responses; Timesaving, efficiency, and convenience	Internet Access; Probably manual process; Time shortage to respond; Mistaken responses	Al-Halafi et al., (2017); Parag et al., (2017); Salazar-Gomez et al., (2017)
Photogrammetry + laser scanning	Easy scanning; Less computational effort; Object recognition capabilities; Convenient for modelling objects; Accuracy in the localisation of edge points; 3D modelling geometry and visual quality; Cameras Self-calibrating	Expensive; Georeferencing issue; Less effective in a crowded site	Alshawabkeh, (2006); El-Omari, (2008); Ibrahim, (2015); Raza, (2017); Agha and Monnet, (2019); Khatiwada and Budge, (2019); Zou et al., (2019); Moselhi et al., (2020)
Laser scanning + UWB	High visibility against fog and dust; Less accumulated error; Ease of need for prior knowledge or control inputs	Accuracy of UWB mapping; High implementation cost	Shahi et al., (2015); Cai et al., (2020); Moselhi et al., (2020)
UWB + Photogrammetry/ videogrammetry	Reliable positioning; High accuracy; Timely information; Less computational effort; Portability	Calibration difficulties; Error propagation phenomenon; Less accuracy against georeferenced technologies	Li et al., (2013); Siddiqui, (2014); Masiero et al., (2017); Ahmad et al., (2018); Moselhi et al., (2020); Shule et al., (2020)
RFID + laser scanning	In 3D modelling: robust recognition and fast positioning; high accuracy in a crowded environment	Poor performance for corner positioning; relatively expensive; objects availability is required	Valero et al., (2012); Valero et al., (2016); Lu and Lee, (2017); Ma and Liu, (2018); Wang and Kim, (2019); Ekanayake et al., (2021)
RFID + WSN	Tags communication; negotiation of RFID; readers together; high positioning accuracy; less energy consumption	Passive sensors; wide range using high energy	Wu et al., (2013); Ibrahim, (2015); Cheung et al., (2018); Ashraf and Osama, (2019); Moselhi et al., (2020)
4D Scheduling Technologies	Complete detail; compatibility with technologies; timesaving. Possible to make future maintenance; easy plan management	High cost: unique apps needed; skill-based	Hartmann et al., (2008); Turkan et al., (2012); Kim et al., (2013b); Pătrăucean et al., (2015); Mirzaei et al., (2018); Dallasega et al., (2019)

keep all workflow tracking evidence for future claims (Feather, 2007; Dhiwar, 2021; Morales and Beis, 2021). However, the sender and recipient can have enough time to review inquiries and resolve any issues in time. While there are many advantages for projects to uptake this class of technologies, there are some limitations. For instance, access to a stable and fast Internet connection is required. The ability to add features using typing is limited, easy typo mistakes on smart devices can happen, and privacy on video chat, depending on the type of project, also is a concern (Leung et al., 2008; Omar et al., 2018). Hence, further dedicated research is required to minimise limitations and risks and increase efficiency in terms of the analysis part.

4.2 Data collection/analysis

Table 8 shows the advantages and disadvantages of these technologies which impact data collection and data analysis. While most of them play the entirely supportive role as data feeding to analytical technologies, some data analysis features can be adopted from them too:

4.2.1 RFID and wireless sensor networks (WSN)

In the integrated system based on RFID and WSN, all assigned sensor nodes can identify and detect tagged objects through readers (Zhu and Cai, 2021). The smart node readers detect the tagged objects to recall them conveniently (Nunnally, 2014; Bae and Han, 2019). However, sensors and RFID tags must communicate conveniently to increase tracking system efficiency and productivity, so targeting and embedding a wide range of sensor nodes with RFID tags and readers is necessary (Ibrahim, 2015; Salama et al., 2021). Furthermore, the hybrid approach of RFID and WSN prepares for better communication between RFID tags, RFID readers, and tag-readers by increasing positioning accuracy and enhancing the tracking system's efficiency (Landaluce et al., 2020).

4.2.2 RFID and laser scanning (LS)

The combination of LS and RFID technologies could be utilised to gather the type of information required from each object or activity (Ando et al., 2020; Fu et al., 2020). In other words, this combination has an acceptable accuracy by measuring angular error and localisation setup within acceptable degrees and a few centimetres. So, for point cloud data acquisition, object recognition is facilitated. Moreover, Table 9 shows some of their advantages and disadvantages: LS and RFID combined can process object recognition out of the point cloud data; hence it would not necessarily be limited to non-structural or structural components. This combination of technology can generate 3D models of each piece of the object on the site (Marocco and Garofolo, 2021). However, some limitations can occur, such as degraded localisation accuracy based on objects' location. For instance, at the corners or blind angles, data acquisition and tracking will be challenging. Creating a database that captures all available things on site is a key predecessor of a complete and accurate model (Khosrowshahi, 2017; Cheung et al., 2018; Yan et al., 2020).

4.2.3 Laser scanning (LS) and ultra-wideband (UWB)

One type of indoor positioning system is called Ultra-wideband. The high bandwidth and high frequency are UWB system features, so a large amount of data can be transmitted during a short period (Svalastog, 2007; Maalek and Sadeghpour, 2013; Zhu et al., 2014). Furthermore, LS measurement accuracy is about 2% volumetric error while, depending on the application, up to a few centimetres in range. Table 9 illustrates a few capabilities and limitations of each of them briefly. Conversely, as a capability, the integrated application of LS and UWB provides less accumulated error and facilitates having prior technical knowledge.

4.2.4 Photogrammetry/Videogrammetry (PVG) and laser scanning (LS)

LS and PVG offer real-time data acquisition capability, reduced scanning time, and robust image procedures. Accordingly, more accurate and acceptable 3D model outputs are achieved (Wang et al., 2021; Sommer and Seiffert, 2022). In other words, these are used as supportive tools for other analytical tools/technologies.

4.2.5 Remote systems (RS) technologies

The current study has reviewed and classified various remote systems (RS) technologies for automated data acquisition and fusion in the construction industry. More specifically, those methods integrate different RS technologies to increase productivity and data accuracy on site. Therefore, according to popularity in data accuracy and affordability, Table 9 provides an overview of those technologies along with some of the benefits and drawbacks such as paring of radio frequency identification (RFID) and Wireless Sensor Networks (WSN); RFID and Laser Scanning (LS); Laser Scanning (LS) and Ultra-Wideband (UWB); and Photogrammetry/Videogrammetry (PVG) and Laser Scanning (LS) (Razavi and Haas, 2011; Boje et al., 2020; Moselhi et al., 2020; Bansal, 2021; Ekanayake et al., 2021; Liu et al., 2021; Naghshbandi et al., 2021; Valinejadshoubi et al., 2021). Moreover, Kopsida et al. (2015), Han et al. (2018) and Álvares and Costa (2018) published that there is a significant growing recognition among a wide range of researchers that utilise visual data technologies/tools to improve communication and measuring of the construction progress. However, they acknowledge that still a lot of work needs to be done to formalise, develop, implement and validate methods based on technologies/tools such as 3D mapping (e.g., BIM) for optimisation of the construction progress tracking (Kopsida et al., 2015; Han et al., 2018; Álvares et al., 2018).

4.3 Data collection/analysis/presentation

The integration of 3D models with project management scheduling tools (PMST) such as Primavera or Ms Project is called a 4D scheduling model (Kakde and Desai, 2017; Romigh et al., 2017; Ando et al., 2020; Asri and Susetyo, 2020; Vanhanen, 2021). As a result, the project team can see how the project is planned, what the final post-construction facility will look like and, at the same time, monitor project time and cost. It has changed and enhanced monitoring processes such as earned value management. Several commercial software packages for project management systems are available. However, Oracle and Microsoft are the most popular providers of project management software, such as Primavera and Ms Project, to schedule and track project progress as accurately as possible (Vanhanen, 2021; Waszkiewicz and Gumienny, 2021). Moreover, most project management tools have a web-based version because they are accessible to onboard users, provide a login, unlimited access to real-time data, and have up-to-date tools/software (Habuza et al., 2020). All are stunning matters unless data acquisition and fusion mechanisms are reliable and upgraded. A most comprehensive review of digital technologies in the construction industry in terms of productivity improvement view is Chowdhury et al.'s (2019) work. So, despite the considerable quantity of publications on digital technologies/applications in the construction industry, studies on the process-based functional roles of digital technologies to directly address delay management through productivity managing or cost control are scattered. Thirty-two identified digital technologies with key functions were compared (Chowdhury et al., 2019). The current study has used those comparisons and summed up those digital technologies highlighted regarding productivity concerns in construction projects. Table 8 and Table 9 list the key advantages and disadvantages of single and combined digital technologies.

5 Contribution and implication of the study

All From the selected literature, a set of insights can be derived for delay management purposes. This involves the shortcomings of real-time process-based technologies, applications, and usability across smart construction industries. In addition, As seen in Section 4, automated technologies for progress tracking (DC/DA) and timely reports (DA/DP) on construction phase are embraced in many research studies and provide various opportunities for the sector regarding increasing or optimising productivity through managing delays, reducing costs or people monitoring. However, managing delays need reliable data which reach out from site by using technologies/tools, therefore issues and challenges of single and combined tools to collect data, analysis data and present data into construction phase are emerging across various projects. In addition, there are gaps in the literature and industry documentation that require further development to demonstrate integrated process of linking compatible technologies to gather for data stage purpose. As follow, some of key areas are accordingly discussed from different vantage points:

- Delay management viewpoint: It must be considered that the captured data from the site through single and multiple sensors must be integrated, screened and analysed accurately. Figure 4 - the proposed framework-illustrates an overview of an interactive dynamic relationship between class (es), database(s) and decision-making layers. It shows how this is essential to be defined and customised within the unique scopes of projects. For instance, in Figure 4, the progress tracking process shows an overlapping between data acquisition (DC) and data screening (DA). It means once finalising data screening, there still needs to be awareness of the source of the data and their level of accuracy.
- Process-based digital technologies viewpoint: Figure 4 depicts a process-based framework of key classes and their applications through the data life cycle. Meanwhile, Table 9 addresses some benefits and drawbacks of digital technologies/applications from a real-time data acquisition and fusion perspective. It means real-time applications, such as timely communication tools, sensory technologies and project management tools, can be used to make real-time decisions. Moreover, all layers are being used, slightly overlapping based on the nature of the data cycle.
- Real-time integrated delay management systems: As seen in Figure 4, the integrated methods might be identified, applied, and validated in the construction industry. This means throughout the project, the process and data life cycle must be monitored and developed based on the project's needs. In other words, delay and risk factors can be monitored and analysed timely and continually by tracking critical indexes such as Baseline Variances; Earned Schedule (ES); Earned Value Management (EVM): Cost Performance Index (CPI), Schedule Performance Index (SPI); and Delay caused/causing item(s) such as lack of resources, clashes, incidents, material, invoices. (Decision-Making layer in Figure 4).

As a result, Figure 4 proposes a blueprint of the framework that shows the key interactive dynamic relationship between class (es), database(s) and decision-making layers which were mapped in three layers, including their tools and technologies as follows:

5.1 Layer 1—Classes

Class 1 (Data Collection) comprises real-time communication channels (or at least with less transmission latency) such as smartphone features and applications or smart devices (e.g., handheld computing) and augmented reality such as HoloLens. Class 2 (Data Screening/Analysis) includes the combined Industry 4.0 technologies/tools such as IoT, robotics, artificial intelligence, BIM, automation, digital twin (Boje et al., 2020; Shirowzhan et al., 2020), sensors and wearables, or some other samples such as photogrammetry + Laser scanning, Laser scanning + UWB, Laser scanning + RFID and Photogrammetry + UWB. Class 3 (Data Analysis/Presentation) presents 4D technologies/tools such as BIM and project management scheduling tools (PMST), Primavera and BI tools (PowerBI, ExcleBI), augmented reality (e.g., HoloLens) and BIM and PMST.

5.2 Layer 2—Database(s)

Layer 2 in the proposed framework (Figure 4) shows a straightforward pre-processing process (into classes), repairing, analysing, and storing the data acquired from the class 1 data streams. Throughout the framework, a relational DBMS is defined to store data and develop analytical query language, which is translatable into structural query language (SQL) expressions. The proposed DBMS has the potential to extend the use of multiple data flowing among classes to 1) record site status progress, document management, scheduling, and quantity of site productivity in construction projects; and 2) analyse delays through the recorded/stored data by decision-makers. Therefore, from a construction management professional's perspective, DBMS design knowledge and its manipulation must be highly considered. In Figure 4, all classes must communicate and collaborate through a central cloud-based database, so new queries can be created to manipulate the scope of the streamed data, which is achieved and screened through class technologies and tools. The framework supports discovering real-time project delays and identifying and analysing construction site activities. As a result, to cover previous review gaps in terms of lack of a process-based view, we found having a database-based framework must be practical relational DBMS as generalised infrastructures.

5.3 Layer 3—Decision-making

Data is raw and constitutes the certainty's values, while information is interpreted from the collected data. However, knowledge is key to bringing up the right actions through the decisions taken based on the generated information (Allen and Terry, 2005). In the proposed framework, layer three can use 4D technologies supported by relevant tools and technologies to enable decision-makers to identify delays and analyse them in a timely manner. Therefore, data should be organised throughout the classes and database to provide a set of usable information. Thus, in light of reached information, timely and reliable knowledge enables decision makers to specify and analyse project progress and delays (Allen and Terry, 2005; Turner et al., 2020). DBMS are vast in use between layers for diagramming of data modelling, a transition of data to reliable information, and definition and design of the required data structure in terms of delay identification (Bilgin et al., 2015; Özyurt, 2018).

To simplify the process, supervisors or leading hands acquire the construction site raw data such as text, photos, and figures with devices such as tablet, phone, or HoloLens. This unprocessed data is supposed to be used for site progress and project status purposes. Moreover, a central DBMS is designed to cleanse and analysis the collected data by running SQL queries continually. These codes convert raw data to processed figures. However, the database links to technologies such as BIM, Sensors, PMST and ERP systems to keep updated project real-time data flow (input/output) including schedule, cost, drawing, project status, and site progress. It means, design changes will be collected from ERP systems and BIM, so DBMS will render these data and compare with site data captured by devices. For instance, it was supposed to have 10 lighting fittings in room "A" through drawing rev 2 but during the update DBMS identify drawing version has been changed to rev 3 with 15 lighting fittings so automatically save previous one and replace 15 as planned. From the planning department, programme (e.g., schedule, resources and cost) will be used as an input and DBMS concurrently check those data with the previously rendered ones. In this example, the schedule says lighting fitting installation for room "A" will take 2 days for 10 fittings, but DBMS will inform planning team that the updated quantity is 15, so planning team will revise duration or with activating permission DBMS will change it automatically and just inform planning team as record. This transaction will be reported through BIM or project management tools (Primavera, MS Project) to project managers (or key stakeholders). They will be able to take action to analysis impacts such as cost and time, and also issue delay notice timely (inexcusable delay—Extension of Time).

Through the proposed process, all involved decision-makers can be on the same page to take strategic decisions on time or at least during a reasonable time period. For this reason, the business intelligence (BI) and other 4D tools will be coming across to present all wrapped up data which processed and analysed already by DBMS. Therefore, the frond end approach (presentation) is also getting updated continually as one of the links to DBMS. Thus, all transactions will be handled concurrently through DBMS. Another view of the proposed process is once supervisors have comments on the new version of drawings or clashes are not removed into site while the drawings rare clash-free, engineering team and site team can communication timely through HoloLens (or other Augmented reality tools). This way will save time and avoid any extra delays regarding corresponding thread even without having engineers into site physically.

This gap recognised through literature reviews and facilitated workshops, it means most of delay have been caused/causing by delaying in correspondences between site team and engineering team. Reviews shown into several projects design team (engineering) is not available, or hard to reach them, thus, they only rely on marked up drawings sent from site and reply site based on them. Furthermore, the BIM team also update models based on clash-free drawings and release them to site for construction. Now, the proposed process engine will notify all parties in terms of any changes and variation that have been happening. So, for any changes are still not clear for site using any AR is the best way that the site team can bring engineering team to site virtually. So, the design team (engineering) can see the room "A" and particular drawing and can figure out what is going on and how clash-free drawings do not work properly. In parallel, the site team also can provide the engineering team with videos, photos and digital marked up drawings which are done through virtual visit. In contrast, the planning team can categories project status and progress in terms of the number of delays that have been caused by different factors such as clashes, drawing RFI delay. As a result, key stakeholders can be monitoring dynamically project progress based on EVM, SVM and resource plan metrics to measure impact of delays and/or risk of potential delay on the project. Moreover, it is crucial to demonstrate the real time root cause of any delays timely to key stakeholders to make them possible for any proper action, thus Power BI would be a powerful front-end analytical platform to show off all analytical metrics coming from the DBMS.

To sum up, the novelty of this systematic literature review is not only focus on analysing previous works to understand regarding what type of digital technologies have been using and how dealing with data stages, but also proposed a framework that has designed an integrated data-driven process including popular technologies to collect data, analysis data and present them. The processed, rendered, and analysed data will be assisted by project key stakeholders to be aware of any problems delaying project life cycle such as 3D models, as-built design, schedule, resource plan, and cost. The details of internal connection and interface among the mentioned involved departments and tools need to have another work.

6 Conclusion

Delay management through tracking productivity (cost and schedule) is still a significant concern in the construction industry. Construction project managers encounter a notable delay in the project life cycle which is caused by design, construction site problems and material. Many technologies are available to assist project key stakeholders *via* digital information flow by providing timely and accurate reports on the construction projects' status. To mitigate the risk of delays, all project key stakeholders need to access timely, more frequent, and precise information alongside updated progress reports including EVM and SVM analysis to track delays during construction projects. Hence, studies are abundant in conjunction with automated data acquired from construction sites that address the mentioned challenge through a more accurate integrated digital technologies proposal. The chosen technologies are presented and compared based on various factors such as data acquisition effort, processing time, affordability, data accuracy and reliability, and scalability. To achieve this goal, the current study proposed the data-driven process framework to combine those compatible digital technologies/tools from design/engineering, planning/scheduling, construction site and analytical presentation/visualisation perspective with the designed DBMS as an engine of framework (Figure 4). As explained, the proposed process includes three layers: classes, databases, and decision-makers. The framework engine (DBMS) has centralised all allocated tools and technologies to each layer. Because the designed DBMS process site raw data, drawings (version, take off qty), RFI, schedule, project costs, resource plan, risk plan which coming from different department and preparing with different tools.

The key role of DBMS is concurrently processing data to identify discrepancies and send proper notice/alert to relevant department(s) to act properly. The one of important advantages of the proposed frame work is being a user-friendly design, entity relationship diagrams provide valuable information for DBMS developers and also is user-friendly for non-technical people to get insight into the data model (Oppel, 2010; Ptitsyn et al., 2016). On the other hand, timely accessible DBMS makes project decision makers possible to be notified of project problems if those causing negative impacts like delays on project completion date and take proper action timely or during the reasonable period. Moreover, relevant key trends, themes and technologies in construction projects and their advantages and limitations in previous literature are allocated in each class. The novelty of this research refers to an integrated "process-based framework" of the data life cycle (data flow) to proceed data stages (DC, DA, and DP) by using the relevant digital technologies alongside a cloud base DBMS as an engine of the proposed framework. From previous literature, this view cut of using real-time digital tools in construction projects for managing data flow in delay purpose has rarely been discussed, so it considered as research gaps and future exploration. Therefore, for this purpose, the process of DC, DA and DP to real-time decision-making should be reviewed from a delay management perspective to achieve timely and accurate objectives in the projects. Purposely, Figure 4 has structured a simple process to 1) identify the progress tracking process from data collection to make a timely report (for a real-time delay management approach); 2) classify the type of technologies/tools used in each of those processes; 3) find gaps and do re-structuring. In simple words, the proposed framework is a real-time integration of data flow to make strategically project managers possible to act on-time about those problems delaying projects. However, it needs more investigation in the future, such as into integrated management systems, relationships, types of entities, sorts of data flow, and so on.

Additionally, the authors could figure out some limitations through systematic literature reviews whether further dedicated research is required to minimise limitations, risks and increase efficiency regarding the analysis part. There is no flawed methodology of using DBMS with compatible tools and technologies. More research is suggested to report how mega projects will deal with big data from data centralization point of view.

Author contributions

Conceptualisation, KR and SW; methodology, KR, MJ, RL, and EG; software, KR; validation, KR, MJ, and RL; formal analysis, KR; investigation, MJ; resources, KR; data curation,

KR and SW; writing—original draft preparation, KR; writing—review and editing, MJ, RL, and EG; visualisation, KR; supervision, MJ; All authors have read and agreed to the published version of the manuscript.

Conflict of interest

Author EG was employed by Mercury NZ Company.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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