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An overview of assessment methods of construction energy consumption

Abstract

One of the major challenges in managing energy consumption in construction sites is to reliably monitor and report energy usage in real time. Given the complexity of construction projects, it is often difficult to keep track of all the assets and equipment being used in a particular project and monitor their energy consumption. To track the energy consumption of construction machinery and equipment at a construction site, it is essential for construction companies to implement a comprehensive energy monitoring system that can effectively capture and analyze the data associated with these assets. In this research paper, we provide an overview of the current state-of-the-art technologies that can be used to monitor energy usage in construction sites by reviewing and analyzing current literature on energy monitoring methods in construction sites. These methods were classified into four main categories based on the technology used to monitor energy usage. Afterward, a SWOT analysis was made to evaluate the strengths and weaknesses of each category and identify areas for improvement in the future. The results presented in this research paper show that there is still a gap in the methodologies to accurately monitor energy consumption in construction sites, and it calls for further research and innovation in this area. This paper aims to deliver a holistic overview of current methods and technologies in energy consumption assessment, which can serve as a reference for future research studies in the field as well as for determining assessment methods for practical applications.

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Keywords: Monitoring energy use, Construction sites, Energy monitoring methodologies, Energy savings.

1. Introduction

The use of machinery and equipment on construction sites is an essential part of the construction industry's operations. However, most of this machinery consumes a large amount of energy from fuels such as diesel or gasoline (non-renewable resources), which negatively impacts the environment. According to IEA (International Energy Agency), “the buildings and buildings construction sector are responsible for 30% of total global final energy consumption and 27% of total energy sector emissions” [1]. For governments around the world, there is a growing need to protect the environment from the negative effects of energy production and use, and the energy consumption is therefore an important factor that needs to be monitored and controlled to ensure sustainable development.

From the construction industry perspective, energy consumption is a significant issue since the cost of running machinery accounts for a significant proportion of the total operating costs of a construction site. Therefore, it is critical to monitor the amount of fuel consumed by each machine and equipment in a construction site to ensure that their operating efficiency is maximized and consequently, operating costs are reduced.

There are currently various methods and technologies available for monitoring energy use on construction sites. These include smart metering systems, web-based dashboards, and energy management software, among others. However, despite the widespread of these technologies, the construction industry still faces big challenges regarding energy monitoring due to the dynamic and complex work environments [2]. Some main challenges are: 1) difficulty in collecting reliable site-based data with some of the current measuring systems [3] in a short period of time since data must be collected from many machines simultaneously performing different tasks, 2) determining the input parameters that influence the most fuel consumption in the construction machinery (CM) [4] 3) accurately calculating the amount of fuel consumed in each machine.

To address these challenges, researchers have been focusing on developing more sophisticated models and methods which can help better monitor and quantify energy usage in the construction projects. Some of these methods consider the manufacturer’s datasheets, database from past projects, etc.; some methods combine the information provided by different types of sensors to more accurately measure the energy used by the machines on a construction site. More recently, the use of artificial intelligence (AI) and sensor networks for energy monitoring is becoming increasingly popular due to their many advantages over other conventional approaches. For instance, IoT technology allows connected devices to communicate with each other. As a result, they can collect, analyze, and process data faster than ever. [5]

Each method has its strengths and weaknesses and should be analyzed carefully before determining which one is more appropriate for a given scenario. Even though some of these methods have shown promising results both in the laboratory and on the construction sites, there is still a lot of research that needs to be done before they can be implemented in the field.

To this end, this research paper provides an overview of the literature on current approaches for monitoring and quantifying energy consumption in construction sites as some limitations of these approaches and their possible implications in the future. Our first section provides a classification of the monitoring methods based on the type of data used to measure the energy usage (e.g., data from sensors or data provided by humans), and the approach used to estimate the total energy consumed by the machine. In this section, we briefly describe some of the key features of each of these methods, along with their limitations.

In the second section, a SWOT analysis was made to evaluate their strengths and weaknesses and identify areas for future research opportunities.

Finally, some ways in which these limitations could be addressed are discussed and future research directions that could be explored to improve our understanding of energy consumption in construction processes.

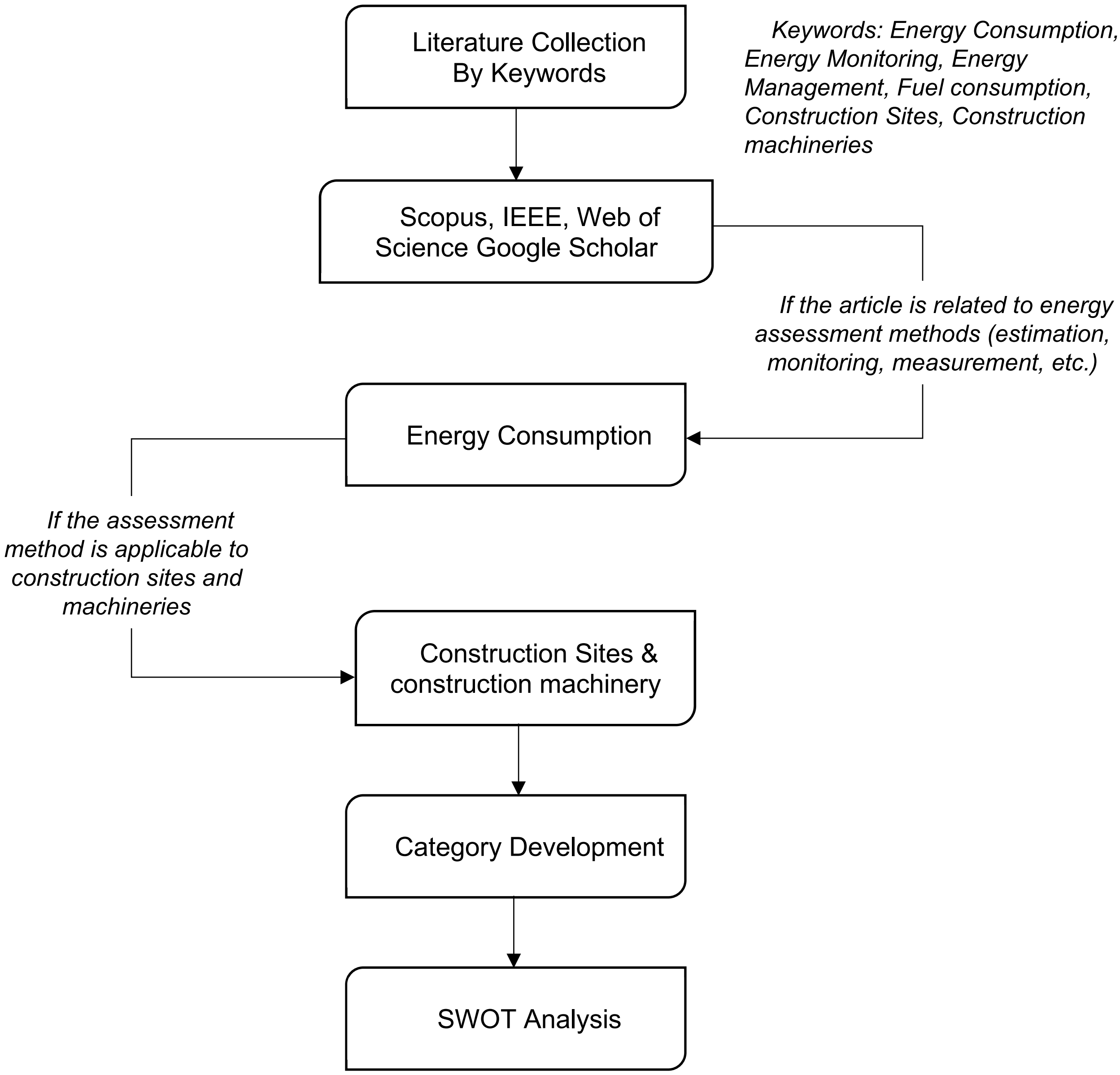


Fig 1: Methodology Diagram

2. Methodology

A combination of systematic literature review and content analysis methods were implemented to investigate the following research questions:

1. How is the energy consumption during construction being assessed (measured, estimated, and even predicted)?
2. What are the current technologies and equipment to assess the energy (either fuel or electricity) consumed during construction?
3. What are the factors to be considered when employing the current assessment methods/models?

As structured in Fig1, the relevant literatures were collected through various academic databases including Scopus, IEEE, Web of Science and Google Scholar, by using the keywords and limiting the publication years starting from 2005. Despite attempting to search the studies of the past 16 years, the number of literatures which are exclusively for energy consumption, is limited. Therefore, we employed the content review for the papers investigating emission on construction sites, a closer context to energy consumption. The studies, in which their energy assessment methods are not applicable to the construction domain, are then eliminated from in-depth reviewing. At last, a total of 19 articles were selected to analyze.

Category development & SWOT: The selected studies were thoroughly investigated. The method of energy assessment in each study, along with their considerations and challenges, were noted in an Excel file with their bibliographic information. The assessment methods are then grouped into categories that are characterized within a similar context in terms of assessment mode, technologies, and equipment and reliability of the result. Based on the resulting categories, the SWOT of each category was identified.

3. Results

Many researchers have studied environmental impacts and emission of construction sites, and there is a considerable number of literatures measuring the emission factors of various construction machinery. It is commonly regarded that the amount of energy consumed is directly related to the amount of emission produced, especially for the construction machinery, for which most of them primarily powered by fossil fuel [6]. As a result, the literatures studying the emission of construction sites, usually attempts to collect the data of direct energy consumption or its potential factors. Therefore, to achieve this study's goal, several relevant literatures on energy consumption as well as emissions were thoroughly reviewed. The methods by which they obtained data on energy consumption are then classified into four groups, namely model-based estimation, instrument-based measurement, vehicle-based measurement, and technology-based assessments. Each category, with its identified SWOT, is discussed in the following sections, with the focus on assessing energy consumption on construction sites.

To encapsulate the results of SWOT analysis for each category, Table 1 summarizes the limitations and the possibilities of the observed energy assessment methods.

3.1 Model – Based Estimation

Model-based estimation systems estimate or predict energy consumption from formulated methods and calculation system by using the appropriate concerning factors, which generally derived from project documentations and operation records.

For instance, *Jassim et al.* [7] proposed a detailed model for estimating energy consumption per hour (or per unit cycle) CO2 emissions by mass haulers in road construction. An optimized hauling schedule, based on the selected haulers' specification and the site and material characteristics, was generated from a planning software called DynaRoad. The plan is then used as a main input for predicting energy consumption and emissions of each vehicle involved or of the entire hauling fleet. Although the result of the proposed model was presented by using the actual data of a case study, their reliability and accuracy was never validated through a real-world consumption data.

Similarly, *Hong et al.* [8] suggested a standard assessment model for energy consumption and GHG emission of building construction by using LCA approach. The consumption and emission of a case study, divided into "material manufacturing, transportation, and on-site construction" phases, were calibrated from the existing lifecycle inventory (LCI) database published by a government authority (Construction Association of Korea, CAK). The database has lifecycle consumption and emission information of building and construction materials. The proposed assessment model evaluates the holistic consumption figure of the overall construction phase, rather than focusing on a specific type of construction equipment. However, it highly depends on the LCI database with the planned or used number of materials and the machinery, which are highly variable in constructions. In addition, the availability of such a database could be the main limitation in certain location. Furthermore, the authors also noted that the proposed model has no considerations for site characteristics except for soil conditions. This, in turn, results in high inaccuracy of consumption and emission estimation, especially when the fuel consumption and emission rate of earthwork operations are highly correlated to the site conditions.

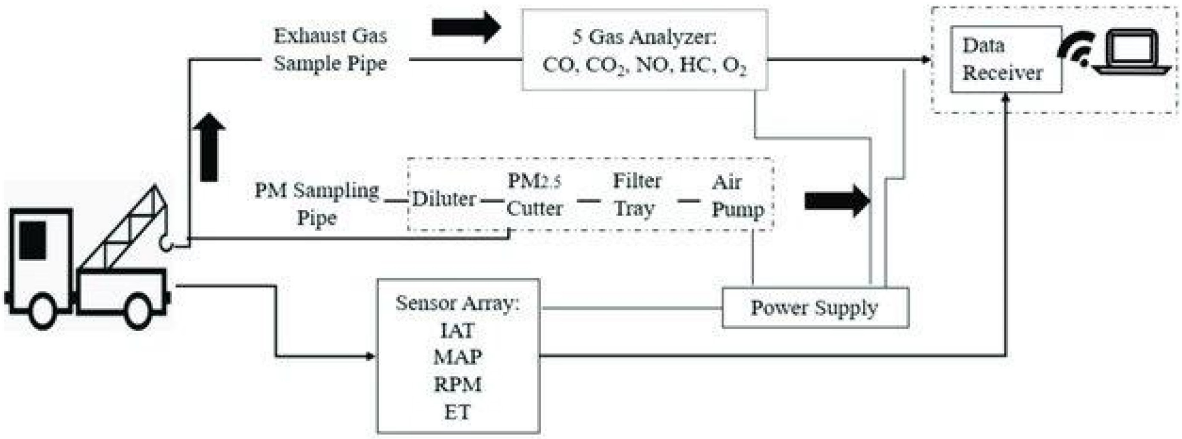
This LCI database approach was also deployed by *Seo et al.* [9] to carry out on-site measurements of CO_2 emissions of a building complex during construction. The evaluation of energy consumption and emission was similarly divided into material production, transportation, and on-site construction phase. Unlike the previous, the LCI was used only for material production while fuel consumption for other two phases was obtained by direct monitoring (e.g. site records) and electricity usage was monitored by implementing smart meter in distribution board allowing more accurate data. Even though the hybrid use of LCI approach and smart meter is presumed to have more accurate results, there is considerable space for improvements to achieve more reliable and robust consumption and emission results.

The preceding models above necessitate some external references and expertise in evaluating. A more comprehensible method was employed by *Li et al.* [6] to calculate energy consumption and carbon emissions of a large-scale public building project during construction in China. The amount of energy consumed, and emissions were mathematically calculated by multiplying relevant parameters such as energy consumption per unit shift derived from the published “Construction Carbon Emission Calculation Standard” and “Consumption Quotas for Housing Construction and Decoration Projects” and the total number of shifts from site operation records. The authors suggested that the method is feasible to implement in similar large-scale projects where there is “the difficulty of collecting data and the inability to measure in the field during the construction of large public building”. The applicability of the method was also demonstrated by calculating energy consumption and emission data of approximately 30 types of construction machinery used in the construction of the case study building. The study then examines the influencing factors of energy consumption and emission by using STIRPAT Model and found that the type of energy used is the most influencing factors on energy consumption and carbon emission. Like the previous model [8], the proposed method did not take the influencing factors such as site characteristics, conditions of equipment and its operation environment into account.

However, research conducted by *Yi et al.* [2] regards those dynamic factors which are highly variable for not only each construction site but also each operation cycle. The study aims to assist construction planners and managers by introducing a simulation model for estimating time-based patterns of energy use and greenhouse gas emission of an earth excavation and hauling operation while considering different operational factors, machine specifications and alternative combination of machines. Based on those varying factors, the data of fuel rate published by Korea Institute of Construction was taken reference to evolve the simulation scenarios. Again, the availability of such reference and its reliability could be the limitations.

As summarized in Table 1, it is observed that some approaches focus on a particular type of consumption, for instance, fuel consumption of specific type of machinery, while some provide an all-inclusive consumption data, i.e., both fuel and electricity consumption of all machinery and site office operations [8] [9].

Furthermore, it is also discovered that some proposed methods generally require the pre-established set of consumption and emission rate information which is not readily available in some locations and even when it exists, its accuracy and reliability is somewhat limited [8] [9] [2]. Similarly, some of the methods which consider the engine data of the machinery [6] [7] [2], rely on the manufacturer’s specifications that are sprung from engine dynamometer at a steady-state and in-lab testing environment. This, consequently, lead to inexactitude of consumption and emission result, particularly in construction sites with varying environment and moving activities. This fact has been highlighted by several researchers [10] [11] [12].



It is also found that the reviewed assessment models share some common characteristics which are (1) although collecting of project and machine information required as input is tedious and time exhaustive, the process is simple and (2) there is a lack in validity and verification of the outcome, especially with the real-world consumption result. The later part is crucial because it is proven that the model-based consumption and emission results are notoriously variant from the actual results measured by field instruments such as Portable Emission Measurement System (PEMS) [12] [13] [14].

3.2 Instrument – based Measurement

The instrument-based measurement methods access the real-time energy consumption data directly from the construction sites during operation. One of the most widely instrument is PEMS for measuring fuel consumption.

The primary use of PEMS is to measure and analyze the emissions of pollutants from equipment and vehicles. Nonetheless, it is possible to access fuel consumption relating from the measured engine data. The system is typically comprised of five gas analyzers, a particulate matter (PM) measurement device (to connect to tailpipe), a sensor array, a Global Positioning System (GPS) and either a tablet or a computer. A DC power supply module is required to operate the system. The main unit which is capable of measuring fuel consumption is a sensor array which includes sensors that can be temporarily installed on the vehicle engine compartment and measures IAT (intake air temperature), MAP (manifold absolute pressure), RPM (revolutions per minute) and ET (engine speed). The engine data measured from the sensor array is then sent to the computer on second-on-second basic and the amount of fuel used (either gasoline or diesel) is generated. Aside from sensor array, an alternative way to retrieve engine data is through Electronic Control Unit (ECU) linked with On-Board Diagnostic System (OBD) although the older model construction machinery and “light-duty gasoline vehicles” probably not equipped with ECU and OBD. A GPS is also assembled to the PEMS to track the real-time data of vehicles’ location, path, position, etc. allowing to observe the operation pattern of the vehicle. A schematic illustration of the PEMS is shown in Fig 1. A complete unit of a PEMS weights about 35lb and usually bulky. However, the upgraded models of commercial PEMS might vary in size and weight.

PEMS is particularly a popular method to measure the real-world emissions data from both light- and heavy-duty vehicles, including construction machinery. It has been widely utilized in evaluating in-use emissions and fuel use of construction machinery, as summarized in Table 2. For instance, *Abolhasani et al.* [14] assessed excavators' field-based fuel consumption, and emissions during operating. *Frey et al.* [16] compared emissions from backhoes, front-end loaders, and motor graders operating in real-world conditions with petroleum diesel versus B20 biodiesel. *Hajji et al.* [13] used PEMS data from 6 bulldozers to validate their developed program for estimating the total cost, diesel consumption and emissions of bulldozers. *Heidari et al.* [12] assessed the real-time emission data of 18 construction equipment by using PEMS and evaluated the result against other emission results from model-based prediction methods including NONROAD 2008, OFFROAD2011 and a modal statistical estimation model.

Rasdorf et al. [17] aimed to introduce a more efficient way of using PEMS by setting out a detailed standard procedure for collecting real-world emissions data from construction vehicles in use. These procedures have been successfully used to collect emissions' data from 39 different construction vehicles. And it is also claimed that "the implementation of a standardized procedure for data collection and quality assurance produced valid data for approximately 90% of the attempted data collection effort". The researchers also pointed out some significant challenges in implementing PEMS for field-data collection, which include weather, operating conditions, and site cooperation.

PEMS can provide considerably reliable and accurate consumption and emission data of real-world, in-operation measurement. It is flexible and applicable to both light- and heavy-duty construction machinery, regardless of the fuel type (diesel or gasoline) and site conditions. At the same time, there are some limitations and factors which need to be considered in using PEMS.

As mentioned by R*asdorf et al.* [17], PEMS is designed to operate in moderate environment and sensitive to adverse weather situations. Data collection is only possible under the temperature between 32F, a freezing point and 90F because moisture in the sample line would freeze. Furthermore, the operating conditions of the construction sites are highly variable both in physical environment and operational aspect. PEMS are heavy and bulky equipment and attached to the external body of the vehicle. They are susceptible to vibrations and improper placement of the unit tends to consequence in malfunction or limits the operational performance of the vehicles. Although the sensor array may be resilient to some extent, those conditions may result in sensor-to-PEMS communication failure. In addition, it requires collaboration from construction sites to install PEMS for monitoring, since data collection from actual field may implicate the operation schedule. Moreover, PEMS are more ideal for collecting real-time emission and consumption data in-use for a short period of time and concurrent monitoring for several construction machinery throughout their entire operation period is laborious and financially burdensome. For that matter, in their study emphasizing on non-road vehicle emission measurement, *Sepasgozar et al.* [3] noted that over the 10-year periods of monitoring and contributing into emission factor inventory, achieving reliable and robust results has remained a significant challenge.

3.3 Vehicle – based Measurement.

The vehicle-based measurement approach involves real-time acquisition of energy consumption related data from the consumption source itself while it is operating under actual site environment. The use of smart meter for electricity usage and the vehicles' Engine Control Module (ECM) or On-Board Diagnostics system (OBD-II).

Over the last few decades, the automotive industry has drastically evolved into extensive automation of vehicles using a network of sensors and computational systems. These sensors are managed by embedded electronic units (ECUs) that are designed to manage a wide range of functions from engine control to tiny fault analysis. It is said that a modern commercial vehicle is equipped with several numbers of ECUs throughout the vehicle and communicate each other via a Controller Area Network (CAN), a type of computer network with standardized, high-speed data communication system. The data from various ECUs is then transported into ECM, a computer system within the vehicle which processes the received information and executes real-time adjustments to the engine and other systems to achieve optimal engine performance with less energy consumption and risks. Additionally, some vehicles are also equipped with OBD-II which links to ECM and a diagnostics software to ensure the emission rate is within the regulated limit.

The use of this sophisticated technology in vehicles enables more efficient energy consumption and, in turn, reduces emission rate, especially in construction vehicles. It has been proven in the study conducted by *Hong et al.* [18] in assessing emissions and energy consumption of dump trucks and wheel loaders. The authors commented that the variability of emission and consumption results by PEMS is in trucks with OBD-II is not as dramatic as in wheel loaders without one.

Despite its capabilities, it is important to note that not all vehicles are equipped with OBD-II. Although there are regulations for on-road vehicles after 1996 in the United States (2001 in Europe) to install OBD-II for controlling emission, non-road vehicles such as construction machinery may not have OBD-II, especially older vehicles. Even when they are available, the level of diagnostic functions may differ depending on the vehicle model and manufacturer. And, the diagnostic software, to decode OBD-II data, is proprietary. Alternatively, a data logger or scanner are used to retrieve data from ECM [19][20]. It is essential to consider the cost of those devices, especially when simultaneous data collection from many CM is required. Another major concern is safety and security issues regarding CAN. Due to its lack of encryption, CAN is vulnerable to cyber-attacks and can jeopardize the safety of the operators and data security [21].

3.4 Technology–based Assessment

The last category of energy consumption measurements presents various approaches which involve using wireless communication technology to remotely monitor and collect real-time and continuous data on energy consumption. Technologies such as Radiofrequency Identification (RFID), GPS, sensors, Zigbee, Bluetooth, and other wireless communication technologies improve the efficiency in construction sites by allowing convenient data collection and remote monitoring [22] [23].

One example regarding energy consumption is the development of an IoT-based fuel monitoring system using an open-source capacitive fuel level sensor [24]. The proposed method was experimented in transit mixers and demonstrated that it is capable to measuring the total operational hours, fuel consumed, average fuel consumption, total amount of fuel filled and removed. The system is practical, low-cost, and open source. On the other hand, the applicability of the system is only suitable for overall fuel usage and location tracking. Improvements for new sensors' technology are required to observe activity-based consumption data.

Closing this gap, *Rossi et al.* [25] instigated the use of a “micro-controlled smart plug” which can recognize the activity-based power consumption. The smart plug is a combination of technologies such as GPS and power sensors, Wi-Fi to track and collect real-time power supply voltage data and the patterns of work cycle, etc. The data are then transmitted and processed on the cloud platform. The proposed system is prototyped for three electricity-powered equipment (hoist, sawing machine and concrete mixers). With fuel-consumption measurement methods, the accurate consumption data of construction sites can be obtained at activity level, operation level and project level. Bearing in mind that the novel technologies such as IoT become fancier and the affordability of sensors becomes greater, IoT is potentially the most feasible option to implement for real-time energy monitoring as well as in other aspects of improving site efficiency [5].

In addition, a closely related technology of IoT, telematics which is a combination of telecommunication and informatics, has been widely adopted to transmit and receive data remotely. In particular, the use of telematics for fleet management is a topic that, despite having some developments in other fields such as transportation and logistics, has not been given equivalent attention in the construction industry. However, in a survey conducted by *Jagushte et al*. [26] for investigating the usability of telematics for construction equipment fleet management, 90% of the participants recommended using telematics in construction.

Taking one more step further from real-time data acquisition through sensors and innovative technologies, there are some research endeavors which attempt to predict energy consumption by using Machine Learning (ML) and field-based actual data. *Pereira et al.* [4] scrutinized to develop a framework to estimate fuel consumption of construction trucks based on load, slope, distance, and pavement type by training the actual data collected from sensors and data

	Strength	Weakness	Opportunity	Threats
Model-based Estimation [1]–[8]	1 Simple and conventional process of data collection. 2 Flexibility - some estimation model can provide machine-level consumption while some can estimate overall construction site energy consumption. 3 Pre- and post-construction assessment 4 No significant upfront cost for energy assessment.	5 Limited access and availability of the public data for reference. 6 Time and resource-exhaustive data collection. 7 Lack of validity in outcomes of proposed model. 8 Requirement of technical knowledge to execute the calculation. 9 Operation environment, vehicle conditions and operational behaviours are not considered fully.		10 Accuracy and reliability of the outcome depends on multiple factors such as the purpose of the estimation model, quality input data for calculation, validity of data source, etc.
Instrument-based Measurement [1]–[8]	11 Reliable, accurate and real-time field consumption data 12 Applicable to both light- and heavy-duty using either diesel or gasoline. 13 Emission data in relation to fuel consumption is assessable.	14 Only fuel consumption and emission can be measured. 15 Susceptible to vibrations 16 Improper placement can result to inconsistency of measurement. 17 Limited implementation for smaller vehicles due to heavy and bulky unit 18 Real-time monitoring for multiple vehicles over time span is restricted by financial and operational conditions. 19 Upfront financial cost. 20 Pre-construction assessment is not possible.	Improvement on smaller and easier installation	21 Sensitive to weather and temperature 22 Corporation from construction site is essential.
Vehicle-based Measurement [1]–[8]	23 Reliable, accurate and real-time field consumption data 24 Both fuel consumption and electricity consumption of the vehicle can be measured. 25 Detail diagnostics of energy consumption pattern related to vehicle' operation mode (idle, moving or specific function) 26 Data synchronisation to a cloud platform is possible where OBD-II is available. 27 Availability of vehicle engine optimisation with less fuel consumption.	28 Not all construction vehicles are equipped with OBD-II. 29 Diagnostic functions differ for each manufacturer, model and year of the vehicle. 30 Manual data collections with data logger or data scanner for each vehicle is required where OBD-II is unavailable.	31 Regulations for non-road vehicle (construction vehicles) to require a standard ECM and OBD-II To improve CAN bus protocol to safer and secure network 32 To improve CAN bus protocol to safer and secure network	33 Safety and security issues of CAN bus
Technology-based Assessment [19]–[27]	34 Flexibility - possible to combine technologies and sensors for measuring both fuel and electricity consumption. 35 Convenient data collection 36 Data synchronisation to the cloud sever and	40 Specialist knowledge for sensor and communication network installation is required. 41 Upfront cost 42 Lack of incentives for construction site to implement.	43 Development of IoT-based integrated energy management system for monitoring energy consumption (machine-based, operation-based, project-based) 44 Incentive scheme for	46 Safety and security concerns 47 Data breaches and transparency

Table 1. Summary of SWOT Analysis

loggers installed on-site with ML algorithm. In similar context, *Jassim et al.* [27] proposed a prediction model using Artificial Neural Network (ANN) to estimate hourly energy consumption and emissions of excavators under various operation conditions. *Fukushima et al.* [28] predicted the energy consumption of new electric vehicles by ML trained with the readily available dataset of old electric vehicles.

Compared to the conventional estimation models, previously mentioned in Section xxx which established upon the assumed dataset while ignoring dynamic conditions, one can perceive that real-world data-driven ML models can predict a more robust and reliable consumption. To achieve the ultimate prediction capability, the ML models need to be fed not only with enough data but also with quality data. Despite having said that, a noteworthy articulation from machine learning models is not having adequate dataset representing the real operation conditions in construction sites to train the model and the difficulty to collect such data for all possible machinery on construction sites in various dynamic conditions.

4. Discussion

As shown in the presented paper above, researchers have put great effort into energy monitoring methods in real construction sites using various techniques, which we classified into four categories: 1) Model-based estimation: This category contains the most conventional approaches, which include static information such as manual field measurements, documentation data collection, etc. These types of methods are flexible in terms of overall energy estimations in construction sites and pre- and post-construction assessments. However, these approaches suffer from various disadvantages, such as the inability to provide real-time results, inaccuracy due to the limited access and availability of public data for reference, and data collection being time-consuming. They rely on certain assumptions such as easy, well-defined relationships or a strong linear relationship between input and output variables. This input requires significant human input and is therefore not scalable.

In addition, this approach generally requires the use of specific modeling tools, which may not be available or affordable in certain regions, especially in developing countries. Therefore, reliable, and efficient models need to be developed that consider the characteristics of construction projects in specific regions and that can reliably estimate energy consumption. 2)Instrument-based Measurement: These approaches use instrumentation for monitoring real-time energy consumption. One of the most widespread uses is PEMS technology, which provides both real-time data and detailed analysis with a high level of accuracy, and it's applicable to light and heavy duty using either diesel or gasoline as a fuel source. However, these technologies are expensive to implement and maintain. Furthermore, they are susceptible to vibration and an improper installation could interfere with the accuracy and quality of the collected data. As a result, they are not ideal for long-term monitoring, and it is not cost-effective to use them for large-scale projects.

3) Vehicle-based Measurement: This category involves the use of vehicles equipped with embedded sensors in the engine and the use of smart meter to monitor and analyze energy consumption during work activities at construction sites. With this equipment, it's possible to get reliable, accurate, and real-time field consumption data. Compared to instrument-based measurement, this category has some advantages such as reduced cost, easier implementation, and maintenance. Some downsides of this approach are that not all CM is equipped with OBD-11 and there's a lack of standardization among manufacturers, making it difficult to compare the data received across different types of vehicles from different manufacturers. Furthermore, data security can also be a challenge since this type of information is highly sensitive and not protected. 4) Technology-based assessment: This category relies on the use

of innovative tools and advanced AI technologies, which provide a more detailed and accurate picture of energy consumption for fast and robust data processing and analysis in real-time. It is also capable of identifying inefficiencies in project management and workflow processes, as well as providing recommendations to improve energy efficiency in pre- and post-construction stages. Data synchronizes to the cloud server where it is processed and analyzed to provide actionable insights on project performance and performance optimization in real-time. However, this approach is pricier than the others and requires in-depth technical expertise to implement it. Moreover, building an adequate database for a reliable pattern analysis from different CM and site construction is challenging as it requires data collection across multiple sites over a long period of time.

Therefore, an ideal solution for the data collection of reliable field data on energy consumption and production during construction is to combine the strengths of the different approaches described above. For example, a combination of automated vehicle tracking (using OBD-11 or GPS) and technology—based methods would allow users to access more detailed information about vehicle movement patterns across different sites and worksites at a lower cost.

Alternatively, IoT and telematics are the most promising technologies with great potential, and it is necessary to develop them further to be more effective and economical in providing accurate and timely information for decision-making purposes.

Machine learning algorithms have tremendous potential to improve the performance and cost-efficiency of the construction industry, but they are only effective when used with other advanced methods and technologies. Nevertheless, there's a lack of an adequate amount of real-world datasets to train the machine learning model.

Finally, we realize that currently there's no standard format for data storage that could be used in the future across different platforms. This complicates the process of collecting data and makes data collection and the analysis extremely difficult and time-consuming. The use of standardized formats would allow the easy exchange of information among various stakeholders in construction projects.

5. Conclusion

In conclusion, the paper presents a thorough analysis of energy monitoring methods in real construction sites, categorizing them into four main groups. Each category has its set of advantages and limitations, emphasizing that there is no perfect solution.

The paper suggests that combining the strengths of these different approaches, such as automated vehicle tracking and technology-based solutions, could provide a more comprehensive and cost-effective solution. It also highlights the potential of IoT and telematics technologies for more accurate and economical data collection.

The role of machine learning algorithms in improving construction efficiency is acknowledged, but the lack of adequate real-world datasets is a significant challenge. Additionally, the paper emphasizes the importance of standardized data storage formats to streamline data collection and analysis.

In summary, while no single solution is without limitations, each of these methods holds the potential to contribute to the development of smarter and more efficient construction sites in the future. Advancements in technology and data collection practices will be crucial to realizing this potential and enhancing energy monitoring in the construction industry.

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