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Big Data Analytics in Civil Engineering : Use Cases and Techniques

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ABSTRACT

Big data analytics has brought about positive change to civil engineering infrastructure monitoring, project control and management, and envisioning smart cities. ensors along with more sophisticated data processing methods enable engineers to gather massive amounts of data which in turn can be utilized making useful decisions, carry out predictive analyses on when machinery might require maintenance, or where resources should be utilized to the maximum. This paper focuses on analysing the way big data is used and applied in civil engineering and the advancement that can be made in safety, costs and sustainability of an infrastructure project. Nevertheless, issues including the quality of data, cost sensitivity, and scarcity of talent are also presented.

Keywords : Large Data Management, Civil Engineering, Maintenance Prediction, Structure Health Monitoring

I. INTRODUCTION

Big data analytics are one of the most revolutionary developments witnessed in the field of civil engineering. When using big data from infrastructure sensors and systems, civil engineers can reduce uncertainty, increase resource efficiency, and improve safety. Concerning civil engineering applications, this paper discusses big data methods in relation to predictive maintenance, construction project management, and smart cities.

II. Literature Review

Big Data Analytics is an innovative resource that has made its way into many sectors to shape the current civil engineering environment. Due to the nature of increasing volume, velocity, and variety of data being generated, the use of BDA for civil engineering has emerged crucial. Civil engineering practitioners have been accumulating large amounts of data for many years, from structural health monitoring systems, to data streaming from smart city infrastructure.

However, traditional data processing techniques are not efficient for this increased complexity hence the need for big data solutions. The existing literature on BDA in civil engineering shows how new approaches that are sweeping across the industry are offering fresh ways of dealing with key problems (Kapliński et al., 2016). In incorporating big data into civil engineering, there are possibilities to make better decisions, increase safety, improve the sustainability of infrastructure as well as using resources efficiently.
Big data was first adopted in civil engineering to enhance construction practice and to handle massive civil projects. In civil engineering construction projects, project management in the past depended on a small volume of data gathered from manual surveys or conventional sensors. These methods had some drawbacks especially in terms of near real-time

availability of data and their links at various levels of the project.

In contrast, big data analytics permits extended direct streams of real time data to flow and avail all relevant information of contractors and city planners to other related interested stakeholders. For instance, smart construction management tools that rely on the big data concept can integrate data different data sources like project schedules or plans, supply chain, environmental data, and even data showing productivity of the workers involved in construction projects (Yeum et al., 2016). These datasets allow predictive models to predict the timeline of a given project, potential risks inherent in the project, and most importantly the efficient deployment of resources.

Figure 1 12 Examples of Using Data Analytics in Construction (PixelPlex, 2019)

Big data has received immense attention and has proven to be highly useful in one particular aspect of logistics; transport and civil structures management. Modern cities face challenges of the current age including traffic jam, pollution and degraded infrastructural facilities. More often, conventional approaches to overseeing these systems are inadequate in capturing the evolving nature of mobility in cities. But big data analytics has made it possible to monitor the transport systems in real-time and gather data from several sensors installed on roads, vehicles and public transport. Traffic flow information, weather conditions, and accidents can easily be integrated to build models that are used to predict traffic patterns and this can recommend traffic conditions that include traffic signals, diversion routes and traffic congestion. Also, live information in the transportation network can be employed to detect decaying infrastructure and track their weakness so that appropriate action can be taken and prevent system breakdown (Alaka et al., 2018). This is a predictive maintenance approach which, in addition to transforming asset management of civil engineering projects, is today greatly used in the management of infrastructures such as bridges, roads, and railways.

Likewise, big data increasingly makes up SHM that addresses the long-term monitoring and evaluation of civil structures, such as bridges, dams, and tall buildings. Past SHM methods include the periodic, visual inspections which are both time-consuming and costly and may be influenced by human factors. Big data analytics, however, use both current data from the sensors installed in structures such as strain gauges, accelerometers, and displacement sensors.

These sensors constantly record information related to structural response such as vibration, stress and displacement that can be used to feed machine learning algorithm and statistical models. Another benefit of this high throughput computation is that engineers will be able to detect the precursors of structural failure, and deterioration patterns, so that the right decisions on whether to repair or replace can be made swiftly. This transformation from a maintenance repair strategy to predictive and preventative maintenance not only enhances safety, reduces cost and increase the useful life of valuable assets.

Another popular subject in the literature is the use of big data in smart city context. Smart cities are designed through the application of digital technology into the physical environment in order to help enhance the quality of life, decrease the negative effects on the environment, and advance the functionality of the cities' systems (Bilal et al., 2016). Big data analytics plays the central role in the above vision as it centralised an enormous amount of data from transportation systems, utility systems, energy systems and waste disposal systems among others.

By using data from sensors, social media, and other sources available within a city it is possible to derive citizen behaviour, energy consumption, waste generation, and many other indicators. This information can then be used in the enhancement of resources utilization, minimizing energy use, and in enhancement of public services. For instance, meter information collected by smart meters can be utilized to enhance electricity distribution while traffic information to eliminate traffic jam and polluted air. In this regard, BDA contributes to the developing of more effective, sensible, and inhabitable urban systems proving more relevancy in the civil engineering discipline.

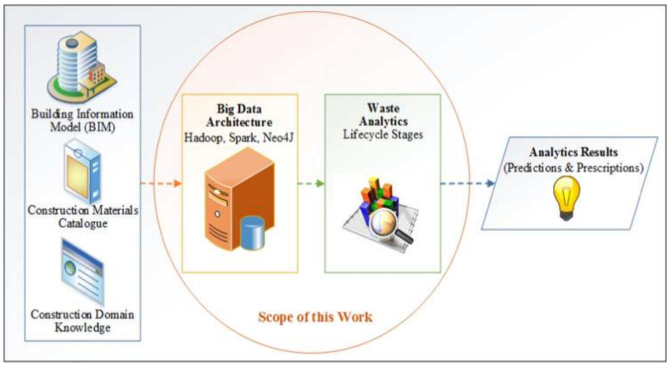

Figure 2 Big data architecture for construction waste analytics (CWA) (ScienceDirect.com, 2019)

However, some challenges still exist as more civil engineering organisations embrace big data analytics. One of the most significant challenges is the compatibility issue related to combining data from multiple sources at construction sites, transit systems, and smart city systems. Each of the datasets may be obtained from different format, system, or platform, which makes it challenging to harmonize and coordinate them. Furthermore, the large amount of data can be problematic in either storage, computational performance, and data credibility. Civil engineering projects also consist many parties whose goals are quite different, thus apply and share data easier than in other fields. Data privacy and security are the other issues which are important especially where and when dealing with sensitive data. For this reason, data management principles and working processes should be set up to let the big data be employed in ethical and protective ways (Rajalakshmi, 2019). The literature also highlights the requirement of creating qualified talent to analyse big data set because civil engineering essentially employs manpower that is qualitatively low in data science expertise.

Existing knowledge of big data analysis in civil engineering elaborates its effectiveness as a innovative and progressive tool in various fields such as construction control, transport infrastructure, SHM and smart city. Machine learning including predictive analytics as well as real time data monitoring are some of the big data that engineers are using to enhance efficiency, safety, and sustainability of the models.

However, the successful adoption of big data analytics is also accompanied by technical, organizational, and ethical issues in civil engineering. In turn, the ever-expanding field of big data and complex analytics methodologies aims to reshape civil engineering practice, enabling more precise predictions, enhanced resource utilization, and to address many of the greatest global challenges in infrastructure.

Big Data Techniques in Civil Engineering

Over the years, for civil engineering practices, big data techniques have become more important, coordinating new approaches to cover data acquisition, processing, and usage across the multiple domains applied to the field. The previously used data collection techniques in civil engineering including manual surveys or use of static sensors have always posed the problem of capturing real-time large data. Investing in the contemporary means, methods, techniques, and applications, for instance machine learning, data mining, and artificial intelligence, civil engineers are now privileged with resources that can analyse a huge volume of data and come up with insights that are somewhat unattainable.

One of them is the IoT sensors that are nowadays implemented in multiple structures to gather constant constancy. These sensors acquire different parameters such as stress, strain, temperature, displacement, and vibration for structural health monitoring (SHM). The information produced by these sensors can be enormous and unless big data concepts are adopted, it would be impossible to make sense of the large volumes of data (Ram et al., 2019). Applying machine learning algorithms allow the engineers analyse the real-time data stream to diagnose failures patterns, and schedule proper maintenance decreasing the probability of infrastructure failures and increasing the life span of man-made structures.

The other commonly used approach within big data analytics in civil engineering is predictive analytics. Forecasting methods involve both a priori and empirical analysis of past data and develop possible future pictures (Alaka et al., 2018). To this, in civil engineering context, it can be extended in transportation planning, urban development and management of infrastructure facilities. For instance, extrapolative models can estimate traffic patterns that in turn could be used in the construction of better traffic control or in the determination of where specific structural enhancements would be most beneficial.

Likewise in construction project management predictive analytics several risks about the timelines of the project, costs and resource allocation could be evaluated. These techniques make use of historical data from previous projects to recognize patterns of risks in current and even future projects hence enhancing on outcomes and costs of projects.

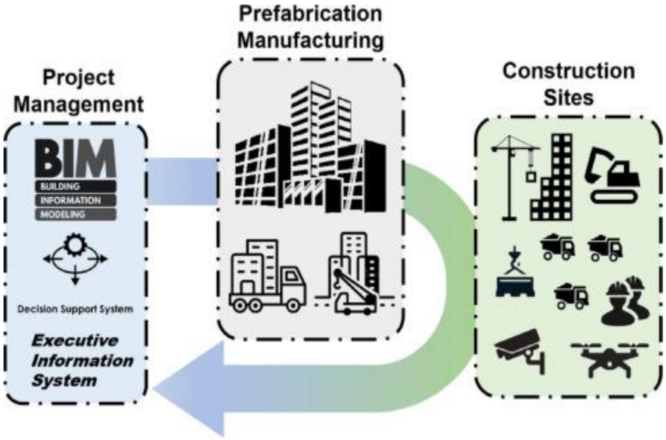

Figure 3 Towards big data driven construction industry (ScienceDirect.com, 2019)

Moreover, big data analytics in civil engineering also applied data mining techniques to search for the undeveloped relations between variety data and features. Data mining is the process of identifying patterns from data and provides useful information by using structured and unstructured data mining algorithms. When it comes to civil engineering, data mining can be applied to analyse large amounts of data coming from construction sites, weather conditions, or from environmental sensors data.

For instance, miner-algorithm approaches can be employed on weather data bases of past years in order to estimate the effects of extreme climate conditions on construction or detect geographical zones that are vulnerable to flooding or soil erosion, respectively. This makes it easier for engineers to reach better decisions in things like where the project will be located, what materials to be used in construction and how the infrastructure project will be developed (Aibinu et al., 2019). Further, the application of data mining brings the potential of enhancing the management of resources available to construction project with regards to flow of the construction processes and operations, which can aid in the success of decision-making in the recognition of possible expenses to be cut back.

Data visualization techniques also become very important enablers in managing big data to ensure civil engineers as well as other practitioners can effectively understand the data. Analogue and digital tools allow the engineers to represent large datasets on graphical tools for better interaction with the masses such as heat maps, interactive dashboards or even 3D diagrams. For example, infrastructure engineers plan and design bridge or roads to examine the structural condition and possible risks arising with help of 3D modelling techniques.

This can result in the more preventive actions and improve the maintenance plans. Furthermore, Geospatial visualization is vital in engineering solutions concerning urban planning to foster smart city advancements because it helps engineers to map its infrastructure, estimate traffic jams and plan effective lands use in large cities (Bilal et al., 2016). Thus, visual representation of various data patterns in a simple and dynamic manner allows the engineers and decision-makers to discern the consequences up to deeper level and act on the resulted information appropriately.

In addition, cloud computing has emerged as a critical driver of big data methods in civil engineering projects because the computing cloud offers the required platform for data storage, processing, and analysis. Civil engineering students can benefit from cloud platforms because it enhances and speeds up the sharing of data and information within the firm's teams and within various locations. Large amounts of data acquired through sensors, construction blueprints and project records can be stored in the cloud, meaning that engineers can access information from other locations; all project stakeholders are informed (Kim et al., 2018). That is why cloud solutions also easily satisfy the need for the scale-up of so many operations during the peak period without the capital expense on the infrastructure of data centres.

This is advantageous to civil engineering where many projects produce large volumes of data that require processing for the success of the project. Besides, the application of artificial intelligence, and machine learning in cloud systems simplifies activities such as anomaly detection, risk evaluation, and project scheduling, thereby improving the utility of big data in civil engineering.

In detail, the technique of big data analytics such as IoT sensors, and Machine learning or data mining or cloud computing in general, are revolutionizing the civil engineering. These techniques empowering the engineers whereby they are capable to control, illustrate and analyse the large quantity of data thereby making the right decisions on infrastructure construction and maintenance, project management and constructions (Bhargava et al., 2018). This is especially so in that the application of big data techniques will continue to be incorporated into civil engineering practices for constructing and improving designs and infrastructures for creating safer and smarter spaces in the built environment. The further improvement of the mentioned techniques would certainly become the key to overcoming new problems and difficulties arising from further description and complexity of civil engineering projects that create large amounts of data.

Use Cases of Big Data in Civil Engineering

In civil engineering applications, big data technologies are applied for estimation of the life time of structures like bridge or road and thus predicting when they will require maintenance. Real-time information on a structure's health, obtained through sensors placed on structures (for example, strain, temperature, vibration), can be analysed via machine learning methods that can predict possible structure failures, thereby allowing for their prevention and enhancing safety (Abounia, 2016). For example, through Random Forest Classifier model engineers can develop how the data from the sensors classify whether it requires maintenance or not according to the input parameters for a particular machine.

```
import pandas as pd
from sklearn.ensemble import RandomForestClassifier
from sklearn.model_selection import train_test_spli
from sklearn.metrics import accuracy_score

# Example data: sensor readings (strain, temperatur
data = pd.read_csv('bridge_sensor_data.csv')

# Features and target variable
X = data[['strain', 'vibration', 'temperature']]
y = data['maintenance_required']

# Splitting data into training and testing sets
X_train, X_test, y_train, y_test = train_test_split

# Initialize and train the model
model = RandomForestClassifier(n_estimators=100)
model.fit(X_train, y_train)

# Predict and evaluate the model
y_pred = model.predict(X_test)
print(f'Accuracy: {accuracy_score(y_test, y_pred)}'
```

Benefits and Challenges

Benefits of Big Data in Civil Engineering:

- **Improved Decision-Making:** Big data gives engineers current information to apply in decision making for infrastructural planning, assessment, and management.
- **Predictive Maintenance:** Big data enables predictive applications of failures or wear in some infrastructures, thus allowing preventive repairs and a decline in durations of unproductiveness.
- **Cost Savings:** Resources are more properly distributed while project planning and control identifies problems that prevent unnecessary losses and expenses during repairs and other operations.
- **Enhanced Safety:** Monitoring and forecasting are carried out all the time to guarantee early identification of risks then enhancing the safety of infrastructure meant for the public.
- **Better Resource Management:** Big data means that material consumption, labour and equipment can be monitored, followed by better project implementation and less expenditure on wastage.
- **Environmental Sustainability:** Big data can be useful to talk about the environment by focusing on energy efficiency and pollution intensity.

Challenges of Big Data in Civil Engineering:

- **Data Quality and Integration:** As is expected, verifying and standardizing data from different sources pose several difficulties.
- **High Initial Investment:** However, there is normally significant cost associated with the processes of setting up big data infrastructure such as sensors and storage systems.
- **Data Security and Privacy:** Reducing vulnerability of sensitive infrastructure data to be exposed or used inappropriately is another.
- **Lack of Skilled Workforce:** It appears that civil engineering companies may face difficulties in recruiting talents proficient in the field of data analysis and inadequacies in machine learning knowledge.
- **Complexity of Analysis:** Often, the interpretation of the results and enabling possible meaningful use of the large amount of data collected can be difficult and require significant time.

III. Conclusion

Civil engineering success stories of big data use have profound values in providing efficiencies, safety, and sustainability. Being able to assess and monitor infrastructure means that engineers are able to prevent high costs and infrastructural failures. However, issues like the quality of data that the analytical tools rely on together with the high cost of implementing these analytical tools together with the need for skilled professionals. In conclusion, the presented study demonstrates that the application of big data analysis is highly beneficial to civil engineering industry and should become more critical as technology progresses towards the future.

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