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An overview of predictive maintenance in relation to 2D and 3D Geographical Information System (GIS) for built environment

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Abstract. Well-preserved buildings can be a great asset to the country, contributing to its economic growth. The lifespan of a building and its assets can be extended through proper maintenance. This will improve the longevity of its function, sustain its performance, and optimize maintenance costs. Predictive maintenance is a proactive approach to maintenance, as it is conducted based on the current operational state of equipment rather than average life statistics. It is generally implemented in building maintenance, machinery, and many other industries. While predictive maintenance has grown in application with artificial intelligence, digital twins, and machine learning, its application with geographical information systems (GIS) and 3D GIS have limitedly discussed. Geospatial predictive maintenance can be realized by integrating the asset's location with its maintenance semantic and temporal information. By incorporating geospatial thinking into the predictive framework, it can help optimize decision-making processes such as allocating maintenance costs based on calculating affected areas, visualizing the location of assets, understanding their interactions with meteorological events and virtual situations. Therefore, this paper will discuss a review of predictive maintenance in relation to GIS and 3D GIS.

1. Introduction

Built environment encompasses places that we live and work such as residential neighbourhoods, transport systems and industrial zones where our needs are satisfied through conducting services such as physical planning, design, development and control from these places and eventually maximised our life quality [1]. Besides that, well maintained infrastructure contributes to sustaining the nation's economy while supporting the nation's societal development which makes maintaining the asset a popular topic worldwide. In 2014, approximately 57% of infrastructure spending in the United States was allocated to the operation and maintenance of existing infrastructure assets [2]. While in Malaysia, buildings maintenance holds significant importance to the country's national agenda. However, the current practices that involve rather corrective practicing deem unsuitable to sustain the longevity of the infrastructure's quality which calls for improvising the maintenance practices through predictive maintenance that detects possibility of faults before its total loss by monitoring the assets' condition throughout its lifecycle and reliance to historical maintenance data such as maintenance logs and sensor readings. Nevertheless, to implement improvise maintenance practices do impose several challenges such as in technical aspects where it consists of inadequate technical capabilities, improper implementation, lack of information and gaps in communication technology.

Information enrichment is important in asset maintenance as it helps providing insight and understanding to what contributes to the certain failure of the asset. Examples of situation that pose significant challenge is to gain insight on the deteriorate of assets along the time and the effects of it in aspect of costs, risks performance of the infrastructure together with other components that relates to it [2]. The deterioration of an asset may relate with geographical element such as weather, terrain and spatiotemporal. Study by [3] underscores the significance of understanding how these geographical factors interact with air quality modeling, reinforcing the understanding that environmental conditions play a pivotal role in asset degradation.Besides that, it is important to have the location of the asset especially for an organization that have large volume of asset at dispersed location. This helps to continuously monitor the assets and aware the effect of the surrounding to the assets. For asset monitoring purpose, utilizing smart components such as sensors do help in detecting potential of failures by providing valuable data regarding the asset's degradation, environment surrounding the asset and its location, yet the data will only become valuable when it gives out meaningful interpretation upon being processed [4]. To manage integrated multisource information such as spatial and semantic information, Geographical Information System (GIS) is capable for this matter, and it is also able to visualize the information due to presence of location information which makes GIS a great information enrichment tool for predictive maintenance and asset maintenance.

In this paper, we provide discussion on potential capability of GIS and 3D GIS in supporting information enrichment to predictive maintenance. The paper is organized into several sections. Section 1 includes predictive maintenance in built environment. Section 2 discussed about enrichment of predictive maintenance with GIS and 3D GIS. Section 3 discussed about challenges in integrating 2D and 3D GIS with predictive maintenance. Section 4 discusses about case studies and success stories and lastly, section 5 will conclude and provide the future direction of the paper.

1.1 Predictive Maintenance in Built Environment

Infrastructure maintenance is fundamental element in ensuring maximum performance of the infrastructure throughout its lifecycle and also to avoid high amount of spending due to unplanned maintenance where the spending can be paid using the building tax paid by the citizen [5]. According to European norm EN 13306-2017, there are two main categories of maintenance type as shown in Figure 1 which is preventive maintenance and corrective maintenance where each type differs in aspect of moment to execute the maintenance. Preventive maintenance is deployed before the failure occurs while corrective maintenance is executed upon the infrastructure's failure [6].

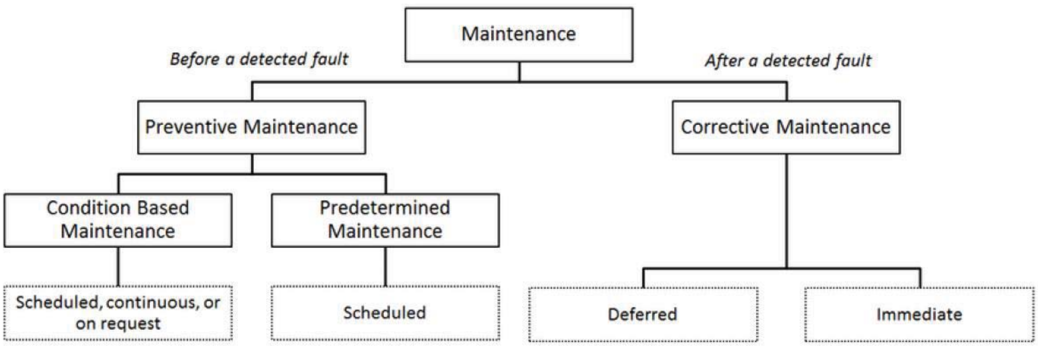

Figure 1. Predictive Maintenance known as Condition-Based Maintenance in Maintenance Execution Type based on European Norm (EN13306-2017).

The limitation of corrective maintenance in accurately estimating time of failure has led to the evolution of maintenance practices towards predictive maintenance which lies within the categories of preventive maintenance and is the extension of preventive maintenance capabilities where it is defined as condition-based maintenance. Predictive maintenance is a systematic approach that monitors assets' condition using historical maintenance data and sensor readings to provide prognoses on possible faults and improve decision-making by predicting trends and correlations through data-driven models like statistics, machine learning, and deep learning to minimize potential downtime. Its capability to process the historical data and predict an event and cause of the events has provided a valuable information that helps in decision making to mitigate the risks of failure [2]. To further define the anatomy of predictive maintenance, the prediction is resulted from assessment conducted through maintenance techniques that comprise of experience-based method, data-driven approach and failure prediction where varies data associated to the asset such as history data and sensor data are used as input for the maintenance techniques [4]. The varieties of information supplemented into predictive maintenance is due to the evolvement in data collection technologies such as sensors, RFID tags and in-built processors to the asset and Internet of Things which makes it capable to stream asset data wirelessly [7]. This rises the potential in improving the accuracy of predictive analytics as demonstrated by [8] that displayed increase in prediction accuracy of an automobile maintenance through its deep learning structured predictive maintenance modelling that have the capability to process multisource data consists of sensor and GIS data. This displays that GIS and 3D GIS can act as an enrichment to predictive maintenance through capabilities of using geospatial data such as spatiotemporal as the input data of the maintenance techniques.

2. Enrichment of Predictive Maintenance through GIS and 3D GIS

Geospatial data refers to information storing coordinates that indicates geographic location of various features and boundaries that is natural and man-made elements on the Earth's surface, and it can be access, manipulated and analysed through Geographic Information System (GIS) [9]. Since built environment infrastructures are attached to earth surface, it can also be defined as geospatial element. This section discusses how GIS and 3D GIS can be used in predictive maintenance through examples from another research.

2.1 Managing integrated multisource information such as spatial and semantic information.

The rise of state-of-the-art technologies causes diverse data sources collected leading to challenges to effectively connect and integrate this sources [2]. By having GIS compatibility to receive these data sources as data input, this information can be processed and analysed resulting to valuable insight which can be shared across industry stakeholders and departments within the organization. This will help stakeholders and person in charge to make informed decisions that can benefit the asset's performance. Besides that, another challenge in managing an asset is to manage the annual maintenance of an infrastructure throughout the time [2]. Integrating information on the asset's condition, historical cost spending and the location of the asset into the asset's cost prediction tool and integrated it into GIS would give an insight about which asset with high and low maintenance cost spending. This would help the infrastructure's owner to prioritize the critical asset and avoid ad-hoc spending as suggested by [10], spatial analysis helps in deciding prioritizing recovery efforts for road assets, at the same time maintenance budgeting can be prepared effectively.

In addition, technical capability is one of the pivotal elements in building maintenance process that can be enhanced with the involvement of Information and Communication Technology (ICT) to ensure that the maintenance works becomes smoother, systematic and accurate [5]. This matter can be further elevated by incorporating GIS into ICT framework as the process and ensuring the maintenance works are accurate and systematics. Integrating GIS into the ICT will elevate the result as more information can be inserted in the same platform.

2.2 Support prediction analysis in spatial aspect.

Certain infrastructure can be situated at disperse locations and its maintenance process can impact other geographical elements as well. To have the insight on how much the area can be impacted, geospatial data is an important element in supporting the prediction tool. This can be further understood from research by [11] that demonstrated the application of GIS alongside predictive maintenance in managing technical infrastructure of water supply system, where the benefit lies by using the result of the water pipes topological analysis conducted using GIS as input to predict the distribution area affected by the maintenance work. Besides that, GIS can be used as visualizing platform for any potential issues by displaying the operational events location with the predictive maintenance details on thematic maps. This fusion of technologies helps to further support decision making process and enable proactive maintenance planning and resource allocation.

There has been limited studies associating GIS into predictive maintenance modelling especially in the scope of built environment. However,[8] has demonstrated the capabilities of integrating GIS and predictive maintenance modelling to predict the Remaining Useful Life (RUL) of automobiles that can be impacted by various geographical factors such as weather, traffic and terrain. The enrichment of geospatial data with maintenance data that was conducted through a deep learning operation showed an improvement to the RUL prediction accuracy.

2.3 Enhancing data insights through 3D GIS.

The data collected would be insignificant if its value cannot be effectively harnessed. Through 3D GIS, it helps in providing visualization about the collected data in real world context. [2] suggested that by integrating the data into the geometric of an infrastructure asset will enhance the data interpretability and analytical capability of the data which can be achieved by integrating sensor data into the BIM models of the infrastructure's structural performance monitoring systems.

2.4 Assists in making rational maintenance decision.

Other infrastructure that involves geographical factors in deciding for the right maintenance practice would be road assets. Location-based thinking were suggested by [10] to be deployed in the Australian state road authorities maintenance practices due to difficulties in executing the right maintenance plan due to weather disruptions. This is because, the spatial capability of GIS helps in providing effective evaluation about the asset situation and the impacts of the environment surrounding the road asset during its encounter with the weather changes. The insight from this evaluation would enable making decision to deploy both predictive maintenance and reactive maintenance based on the suitability of the asset locations which makes GIS as a resilience assistance in making rational decision.

3. Challenges in Integrating 2D and 3D GIS with Predictive Maintenance

Despite the potential benefits reaped from the fusion of GIS and 3D GIS with predictive maintenance, there are few hurdles and research potential to implement this integration.

3.1 Lack of Information and its data update

One of the challenges that can hinder the progress of delivering effective maintenance action is the lack of information resulting from outdated system lacking with information and technology updates [5]. This matter can be attributed to inspection practice that conducted irregularly and inconvenience manual inspection to a large-scale infrastructure, making it taking times to locate all of the assets within an infrastructure which ultimately affect the integrity and completion of the asset registration [2]. To provide an effective maintenance service, key players in asset management should play their role in ensuring information and communication gaps are contained by having data collaborations with the stakeholders and departments within the organization. Besides that, it is also helpful to improvise data collection techniques by using state-of-the art technologies and geomatics technologies to obtain necessary information such as location and capability to monitor the infrastructure's performance. Current technique of data acquisition such as Terrestrial Laser Scanning (TLS), Unmanned Aerial Vehicle (UAV) [12] and Videogrammetry [13] would also help in tracking asset maintenance and monitoring.

3.2 Data Integration and Management

Commonly GIS can accept varieties of data input such as geospatial data, remote sensing, Global Positioning System (GPS) data, land survey data. As long as the semantic information is attached with coordinate information, it can be utilized in GIS. However, it is acknowledged that varieties of technologies are used to collect data of an infrastructure such as sensors and Internet-of-Things devices may not be directly compatible with GIS due to different structure and format. Integrating GIS with these new data sources would require continuation of research. Additionally, data compatibility is not the only concern as the management of heterogenous data sources is also crucial for data storage. To ensure comprehensive information can be supplemented into predictive maintenance for meaningful analytics, it is necessary to consider a scalable and dynamic database solution.

4. Case Studies and Success Stories

The benefit of integrating geospatial technologies with predictive maintenance has been acknowledged in industrial application. The case studies comprise of user's success stories from the commercial product of predictive maintenance and GIS.

4.1 Managing Asset Portfolio

The challenges in maximising the use of the assets and planning for financial resources have caused the highways department at Hertfordshire County council to elevate their asset management practices through full asset lifecycle prediction modelling where the prediction enables running simulation to obtain insight on the maintenance cost based on different scenarios and be visualized using GIS due to the presence of assets' location information [14]. This integration of technologies has allowed the information to be presented visually in the form of map together with information from the prediction modelling and the implementation has resulted the organization able to make smart decisions and help in convincing stakeholders to provide maintenance funding.

4.2 GIS as data source for Predictive Modeling

Next, the integration of technologies was adopted by Golden Plains Shire council that used varieties of commercial information systems such as AssetAsysts and SynergySoft which is Asset Information Systems platform alongside GIS [15]. The varieties of data sourcing from different platform has raised the concern on sustaining the data integrity from single source of truth which makes the the organization migrate the data into Enterprise Asset Management solution from Brightly that offers numerous services. To accommodate the services, existing data that is managed in GIS were used as input into the asset lifecycle prediction modelling which has resulted the council capable to prioritize maintenance operation based on the insight of the affected area [15].

4.3 Integration of 3D GIS and BIM potentially elevate Predictive Maintenance

By integrating 3D GIS and BIM, valuable data enrichment can be achieved from both platforms, leading to improved analysis results. This integration facilitates the utilization of techniques like nearest neighbors queries [16] and the incorporation of essential topological information [17], further enhancing the depth and accuracy of the analyses performed. Integration of 3D GIS and BIM allows for data enrichment from both platforms which can enhance the analysis result. The benefits of integration have made it as a potential solution to numerous situations as display in figure 2 where predictive maintenance is also listed among it. While there has been limited implementation of 3D GIS spesifically for predictive maintenance, several case studies in Norway, Milwaukee and Ohio summarized by Geospatial World [18] regarding integrating 3D GIS and BIM included in this section can be related with predictive maintenance.

Figure 2. Integrated GIS & BIM as potential solution to predictive maintenance [17].

In Oslo, Norway, a conceptual design of the route was created in Autodesk Infraworks 360 while the terrain conditions along the proposed route together with information about the elements surrounding the proposed route such as the natural resources, geology, agriculture, land, and forestry was created using 3D GIS solution. The information managed in 3D GIS was then used in Autodesk Infraworks 360 to run 3D scenarios for route planning as shown in figure 3. The landscape along the under planning route are diversified and contains different geotechnical needs that calls for necessity in displaying information in 3D model. The integration of data has resulted in enhancing the decision-making process due to the comprehensive route planning. Continuing this method even after planning, the asset can be continuously monitored, and the data can be supplemented into prediction modelling. Besides that, Milwaukee Metropolitan Sewerage District had its facilities plan prepared through the integration of three technologies which is LiDAR as the survey tool, BIM as the platform to prepare the as-built city planning and 3D GIS as the platform to provide easier information accesibility to the stakeholders and also to enhance the facilities management due to its capability to integrate data sources from the varies technologies as shown in figure 4.

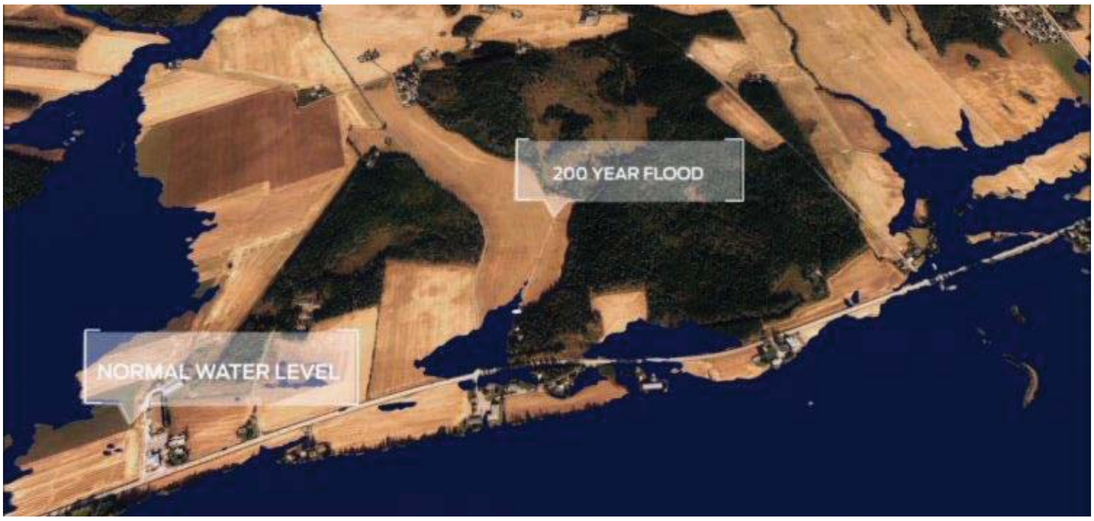

Figure 3. 3D model of the landscape along the route under planning [19]

Figure 4. 3D model of sewerage system managed by Milwaukee Metropolitan Sewerage District in ArcGIS Engine application [20].

While in Ohio State University, ArcGIS was opted for data collection, management and planning of the universities' infrastructure while the 3D model was constructed based on the 2D drawings in Autodesk Revit. The integration then data to be constantly updates which resulted the infrastructure able to be monitored in aspect of its energy consumption and its sufficient in numbers to provide the service to the whole university space. Lastly, in developing the Norway Railway Follo Line, the tunneling process did involved creating prediction model to have the insight of areas that could be affected with the structral noise due to the tunnel excavation with 3D model of the tunnel were used in the prediction model [21].

Based on the case studies earlier, the integration of 2D and 3D GIS with predictive maintenance has enhanced the preparation of the assets' portfolio due to the information enrichment, capability to visualize the information in geographic area and also the capability of 2D and 3D GIS in providing a platform for easier information accessibility to every level of stakeholders. The information enrichment has provided valuable information for predictive maintenance analysis which has resulted in smart decision making at operation and financial level which further helps in making short-term and long-term planning due to comprehensive information available.

5. Future Directions and Conclusion

Earlier the discussion has point out how 2D and 3D GIS potentially enriches predictive maintenance in four aspect which is in managing integrated multisource information, as a support to the predictive analysis, as an enhancement in data insights through 3D GIS and as an assistance in making rational maintenance decision and supported with industrial applications. Despite the potential benefits, the integration of 2D and 3D GIS into predictive maintenance would require extensive research in order to successfully implement it due to crucial challenges such as in aspect of data integration and data management which is a very important to be catered for. [22] also highlighted that the application of various technologies has brought a challenge in combining the data output seamlessly together which this matter needs to be tackled within the scope of data interoperability.

Within predictive maintenance and GIS, there are several associated emerging technologies to further elevate the performance. The technologies can be categorized to serve several processes in predictive maintenance as shown in table 1 such as data collection, data management, data analytics and visualization & simulation. Within data collection, application of sensor to understand infrastructures' behaviour has been actively conducted such as historical data of previous building systems' behaviour alongside RFID, TLS and UAV [12]. Meanwhile, in data management, ontology graphs were proposed to integrate data from different systems such as FM, CMMS, BMS and BIM to cater the wide range of buildings [23] and also Internet of Things as medium to stream infrastructure data wirelessly [7]. As for data analytics context, application of Artificial Inteligent, Machine Learning and Deep Learning[8] are emergingly conducted to enhance the predictive maintenance modeling. In aspect of visualization & simulation, Building Information System (BIM), GIS, 3D GIS and Digital Twin [24] application has shown as upward trend where BIM is used to model the asset at detailed level, while 2D and 3D GIS allows for integrating BIM and other data sources. The 3D model can be further enhanced with real-time sensor data, statistical model relating to analyzing the condition of the asset to make it digital-twin ready as demonstrated by [25] in monitoring the sensor data trend that focusses on mechanical, electrical and plumbing (MEP) components of building facilities as shown in Figure 5 where a plug-in for sensor data were applied in Autodesk Revit.

Table 1. Technologies in predictive maintenance processes.

Predictive Maintenance Process	Technology
Data collection	Sensor, RFID, TLS, UAV
Data management	Ontology graph, Internet of Things
Data analytics	Artificial Intelligence, Machine Learning, Deep Learning
Visualization and simulation	BIM, GIS, 3D GIS, Digital Twin

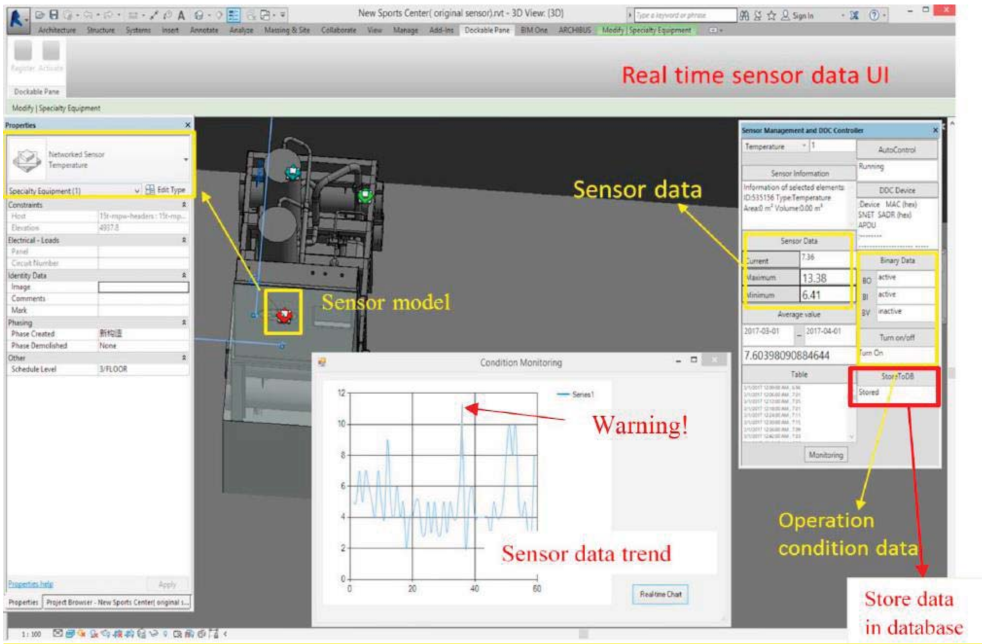

Figure 5. BIM as visualization platform in accomodating sensor data to the 3D Model [25].

Based from technologies from table 1, it opens research possibilities in developing new database structure that can manage the input sources coming from the said data collection technologies and develop capability of predictive modelling in receiving 3D GIS data which [8] addressed that the GIS factor has not yet been considered in Remaining Useful Life modelling which is a predictive maintenance modelling despite it having impacts on the equipment and system lifecycle. The implication upon success in addressing this matter would generate meaningful insight during the predictive maintenance process due to comprehensive set of information being supplemented into into the predictive maintenance analytical tools.

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