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ASSET DIGITALIZATION MODEL AND ASSET HEALH MANAGEMENT

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Abstract:
Despite advancements in technologies like digital twins, asset digitization remains a significant challenge. The core issue lies in accurately and comprehensively determining how assets adapt to the management of complex systems introduced by digitization. This gap in understanding and executing asset digitization affects the organization of asset-related information. Digital assets are vital components within an interconnected digital ecosystem, not just mere pieces of equipment. Without a clear comprehension of how these assets integrate and function within this digital framework, our decision-making and management capabilities are impaired. This leads to operational inefficiencies, increased costs, and a decline in service quality and infrastructure reliability.
This article aims to tackle this challenge by focusing on asset digitization. It provides a practical example of advancing this field through the integration of various models. This involves defining and categorizing assets based on established standards, assessing asset criticality, and merging IoT-based monitoring models with the Asset Health Index (AHI) model. This integration provides a comprehensive view of asset digitization, addressing different levels of complex asset system management. It facilitates better connections between real-time monitoring and a deeper, long-term understanding of asset conditions and performance. The resulting synergy improves the effectiveness of asset digitization strategies, particularly in critical areas like infrastructure management.
The article presents a concrete example: the digitization of a bridge. This case study demonstrates how these practices positively impact asset management and maintenance during digital transformation, enhancing the safety, efficiency, and reliability of our digital infrastructures.

Keywords: Asset digitalization, Digital Maintenance, IoT, Asset health indexing, Civil infrastructure digitalization, Bridge Maintenance. INTRODUCTION

1. Introduction

1.1. Digitalization of assets

This paper explores the concept of asset digitalization, adopting it as a comprehensive term that includes both asset data design and the transformative processes that create new value (Gong and Ribiere 2020). While recognizing the complexities in the terminology of digitization, digitalization, and digital transformation (Raza et al. 2023), this work focuses on three key aspects:

- *Asset Digitization*: This involves establishing the fundamental data and information model for an asset, creating a detailed digital counterpart.
- *Asset Digitalization*: This goes beyond simple digitization by generating new processes, starting with the creation and continuous updating of the digital counterpart. The emphasis is on enhancing the asset's value proposition and management through new processes, which may not solely depend on current digital technologies.
- *Digital Transformation*: The paper positions itself as a contributor to digital transformation by addressing its broader impact on business and society, aligning with the wider vision of enterprise transformation and its influence on the digital society.

1.2. Digital Maintenance

The digitization of maintenance, within the broader scope of asset digitalization, is crucial for advancing digital transformation. This is evidenced by the extensive use of IoT platforms and Prognostics and Health Management (PHM) techniques in

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maintenance (Guillén et al. 2016; Compare et al. 2017; Errandonea et al. 2020; Marquez et al. 2020), which enable real-time asset degradation monitoring through extensive data collection.

Asset digitalization necessitates a technical design within an IT architecture that integrates various systems and platforms. While digitalization solutions often originate from a technological perspective, a maintenance-focused approach is essential to complement this view. This approach ensures the durability and reliability of digitalized assets in line with broader business objectives. It involves understanding and managing the digital functionalities of the IT solution and overseeing end-to-end processes for data and model handling, all centered on maintenance needs, without delving into specific architectural designs.

Considering the role of end users, information system providers strategically design their technical and commercial offerings around platforms and apps. A platform offers essential digital services to support end-to-end processes, similar to IoT and cloud platform concepts. Apps are connected to core functionalities desired by users, requiring a platform for seamless integration and operation in today's complex industrial systems. Intelligent Asset Management Platforms (IAMP) gather and analyze data from industrial assets, typically falling into categories like Enterprise Asset Management (EAM), Asset Performance Management (APM), and Asset Investment Planning (AIP).

In this context, a visual tool (Figure 1) suggested by Crespo Márquez (2022) integrates the Input-Process-Output (I-P-O) schema with the need for multiple models and apps throughout the comprehensive maintenance process. This representation transforms raw data from various business systems into specific models crucial for different aspects of asset digitalization. The I-P-O process aligns with the ISO 14224:2016 framework, with each block representing a function (e.g., ETL, Database, IAM, AI, and BI) to ensure an efficient approach to digital maintenance management. These functions use models to generate outputs linked to various IAM apps, supporting tasks related to each phase of the maintenance and asset management process.

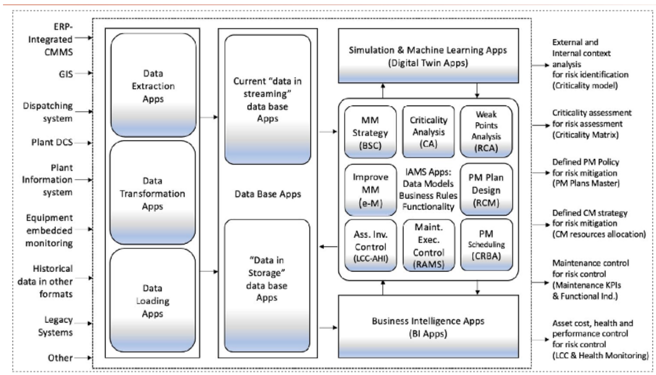

Figure 1. Schema of digital maintenance framework proposed by (Crespo Márquez 2022)

The diagram in Figure 1 illustrates a concept that not only identifies relevant apps across the full scope of management, from strategic to operational levels, but also clearly differentiates between apps and IT functional blocks. This approach is based on the framework for asset and maintenance management initially introduced by Crespo Márquez et al. (2009). This framework, extensively used in the management of network utilities through information technology systems (Gómez Fernández and Crespo Márquez 2012; Serra et al. 2019), has evolved to support both digital maintenance and the design of digital twins (Crespo Márquez et al. 2020; Crespo Márquez 2022).

1.3. Reference architectures

ISO/IEC/IEEE 42010:2011, titled "Systems and software engineering - Architecture description," broadly defines architecture as "the fundamental structure of a system, including the structure of system components, their relationships, and the principles and guidelines that govern their design and evolution over time" (ISO/IEC/IEEE 42010:2022 - Software, systems, and enterprise — Architecture description). In systems engineering, architecture is crucial for offering a framework that describes the interactions and organization of system components to meet specific objectives.

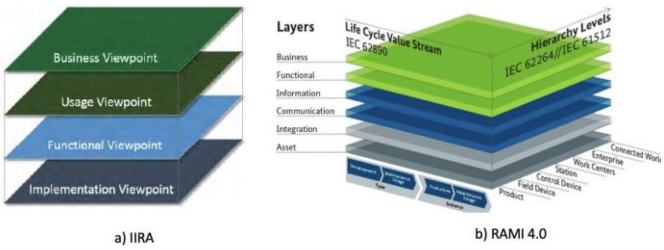

Figure 2. Layered reference architectures: a) IIRA; b) RAMI 4.0

This work primarily references RAMI 4.0 and IIRA (Figure 2) due to their significant influence and widespread acceptance in both academia and industry. These architectures share fundamental principles and approaches crucial for addressing the challenges of digitization in modern industry. They employ the concept of layers to structure systems, which facilitates modularity, flexibility, and incremental updates. RAMI 4.0 introduces two axes—lifecycle and hierarchy in system integration—while IIRA offers a more streamlined perspective. A significant contribution of RAMI 4.0 is the introduction of Autonomous Asset Services (AAS), which plays a vital role in the digital transformation of the industry, as elaborated in the digital twin section. Additionally, RAMI 4.0 explicitly includes the asset and system lifecycle, a critical aspect that needs to be managed effectively in the digitization process.

2. Use case

Bridges, critical in transportation infrastructures, present challenges in Total Expenditure (TOTEX) management. Controlling bridge condition is crucial for holistic management, impacting both individual bridges and the entire asset portfolio. Current tools for effective infrastructure management are limited, and climate change adds urgency to control demands, creating uncertainty in evolving conditions.

Most bridges lack a real-time online monitoring system. Affordable IoT networks enable widespread monitoring, generating extensive data requiring advanced analytics for meaningful insights. Thorough data interpretation enhances understanding and issue identification. Integrating data from multiple bridges offers a global perspective, aiding in predictive model development.

Due to a low initial level of digitization of bridges, during their operation and maintenance (O&M) phase in the middle period of their life cycle, this case study aims to answer the following research questions:

- How can a model-based approach effectively digitalize bridges for maintenance and management?
- How can the combined use of an IoT platform, short-term monitoring models, and long-term models like AHI enhance bridge digitalization and management?

The asset digitization process introduces a set of four models addressing different aspects of asset digitization and management for bridges. Firstly, the Asset Definition Model offers a comprehensive framework capturing the complexities of bridge data in various systems. Secondly, the Asset Criticality Model prioritizes bridge assets based on their criticality. Thirdly, the Bridge Monitoring Model demonstrates how IoT networks and signal integration enable real-time monitoring. Lastly, Intelligent Asset Management Models are designed to estimate the health index of bridges.

2.1. The Asset Definition Model

This model describes the comprehensive asset data/information which is implicitly present within the diverse information systems and apps currently utilized for the asset management. Takes the IEC 81346-1:2022 standard and ISO 14224:2016 as guidelines for this purpose.

The proposed asset definition incorporates four distinct aspects, or specific ways of viewing an object:

- Physical Asset Registration Code. A physical asset code refers to a tangible object or entity that can be touched, seen, and measured.
- Asset Class. Connected to the assets' technology and to the definition of technical aspects unique to the asset, regardless of its final functional location. Subclasses (or types as per the IEC 81346 standard) can be utilized to detail groups within a class, establishing distinctions within the same class.
- Asset Functional Location. Refers to a specific physical or logical location where an asset is installed or used.

- Asset Reference System. The choice of a coordinate reference system for an infrastructure system or network is influenced by factors such as location, precision requirements, and available resources.

According to the four dimensions necessary to establish the asset definition model, the bridge under study has a specific physical asset registration code, a particular asset class and subclass, is located in a specific functional location and geolocated under an established reference system.

2.2. The Asset Criticality Model

An asset criticality model is pivotal in infrastructure management, enabling the prioritization of assets based on their criticality and importance within the organization. This analysis, crucial for risk reduction, must be meticulously conducted, considering factors such as large-scale applicability, consistency with the scope, and compatibility with changes and the asset management system (Jinzhi et al. 2022).

Once the criticality of assets is determined, the framework facilitates integration with other models. This includes the model for establishing a preventive maintenance plan, specifying tasks and their frequency (using methods like RCM, MTA, RCBA, etc.). It also connects with the asset monitoring model, particularly recommended for critical assets with significant impacts on infrastructure effectiveness, efficiency, and performance. Additionally, it links with models for establishing optimal scheduling and resource allocation for a maintenance plan, as well as the model for examining assets to study their degradation and life cycle cost, encompassing the asset degradation and life cycle cost models.

Digitalizing bridges allows for more effective management, real-time monitoring, and a comprehensive assessment of their condition, which is essential to ensure their performance, safety, and durability over time. Additionally, the risk associated with the functional failure of a bridge not only impacts infrastructure but can also have serious implications for public safety and health, underscoring the urgency of implementing digitalization models to mitigate this risk.

2.3. Bridge Monitoring Model

The digital transformation of an asset, particularly those requiring or benefiting from state monitoring, is accomplished by connecting it to data obtained from the physical world through customized monitoring solutions. Developing an asset monitoring model is a complex process that involves signal integration and the creation of a comprehensive Extract, Transform, Load (ETL) process, which converts signals into valuable asset-related information. Advanced systems perform this transformation by deploying sensors via an Internet of Things (IoT) network. This network comprises sensors, nodes, and cloud computing, with nodes playing a crucial role in grouping sensors, ensuring effective communication, and transmitting data to cloud platforms and applications.

The proposed design is based on an IoT framework that includes acquisition and local processing layers at the measurement points (sensor nodes), an information transport network, and a processing server responsible for hosting essential services for processing, exploiting, and presenting information to end-users (Figure 3).

To digitize the monitoring process, information from the strategically located IoT/Cloud network points on the bridge is integrated. The use case solution combines both hardware and firmware design to support local processing, device control, wireless communication, data storage, power supply, sensors for real-time structure monitoring, real-time operating system tasks, and sensor monitoring tasks, along with local information processing and wireless control.

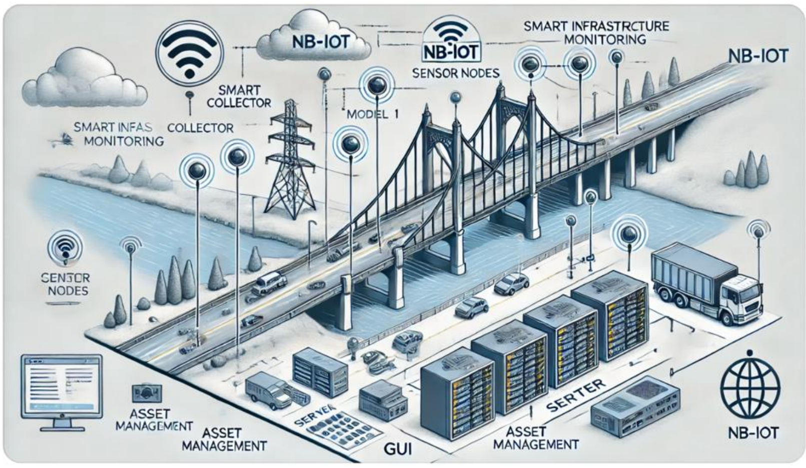

Figure 3. The IoT Network

The server plays a crucial role by centralizing the processing and management of monitored structures. To adapt to scalability, a microservices-based development is adopted, performing tasks such as gathering information from deployed nodes, storing it in a database, and processing data according to different asset digitization models.

2.4. The Intelligent Asset Management Model

Once the information and data from the asset are captured, processed, and stored, and the critical asset is appropriately structured with its operating and maintenance conditions monitored, it becomes necessary to connect data models with human knowledge and reasoning to digitize the decision-making processes. This digitization is achieved through intelligent asset management models embedded in the Intelligent Asset Management Platform App (IAMP App) (Marquez et al. 2020).

In the framework proposed by Crespo Márquez (2022) in Figure 1, various decision-making processes are outlined, including Root Cause Analysis (RCA), Reliability-Centered Maintenance (RCM) or Maintenance Task Analysis (MTA), Condition Based Maintenance (CBM), Maintenance Resources Optimization models (MRO), Reliability, Availability, Maintainability, and Safety Analysis (RAMS), Asset Health Indexing (AHI), and Life Cycle Costing (LCC).

Within the IAMP App, these intelligent asset management models are configured. By interacting with simulation tools or artificial intelligence, they enable personnel responsible for the operation and maintenance of the asset to make informed short-term, medium-term, and long-term decisions.

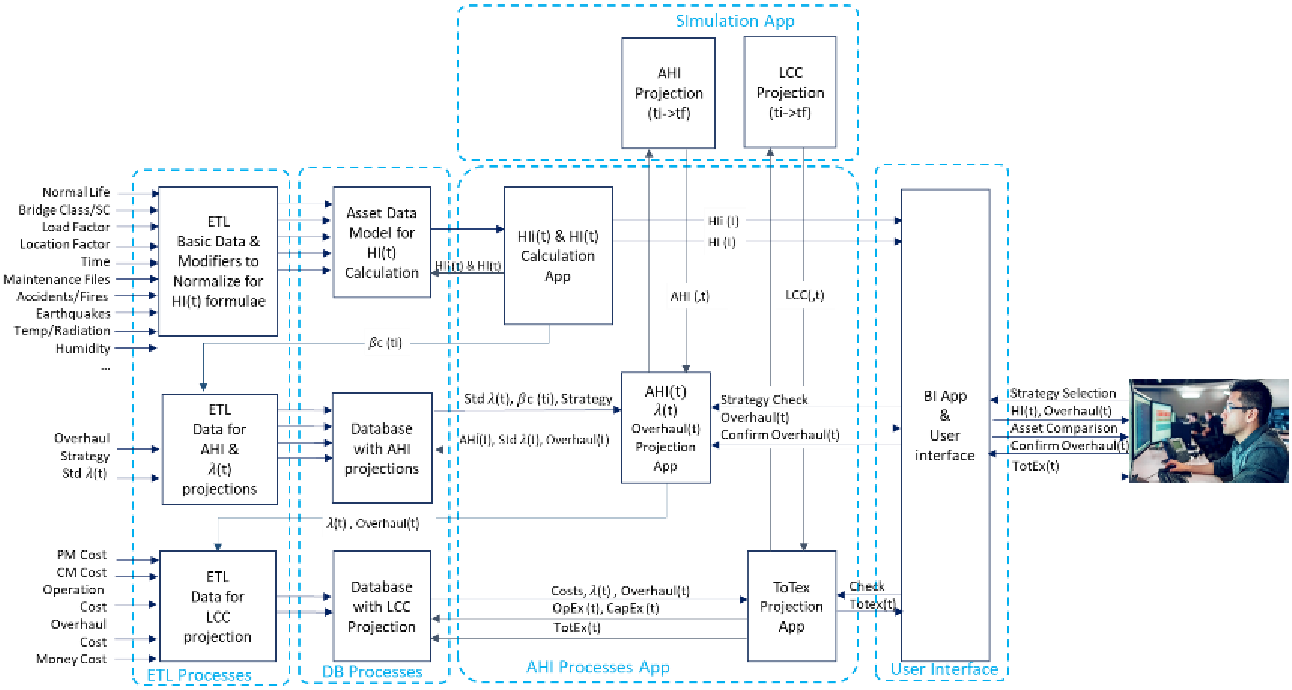

Figure 4. The AHI model presentation using the DMM framework.

In the proposed use case for the digitization of the bridge, the ETL processes, database processes, and Intelligent Asset Management Systems are integrated, supported by mathematical and simulation modeling. (Simulation App), and facilitating the representation of results in business intelligence tools (BI App/User Interface).This integration of various processes, as illustrated in Figure 4, enables the following:

- Determining the Bridge's Health Status: By calculating the Asset Health Index (AHI), it supports short and medium-term decision-making regarding necessary operational and/or maintenance activities based on the asset's current condition.
- Projecting AHI with Simulation Tools: This allows for medium and long-term decision-making by comparing different scenarios and potential strategies for major maintenance or overhaul of the analyzed asset.

- Estimating the Asset's Life Cycle Cost (LCC): This estimation considers past and projected operations and maintenance activities throughout the asset's useful life.

The integration with the IoT network enables the processing of monitoring data from the platform, facilitating the calculation of input indicators for the proposed health index model. The model's robustness allows for flexible validation and recalibration of processes to accurately reflect the asset's condition, thus refining decision-making.

In a case study example, the health index is calculated for four bridges of different classes, technical locations, and operating and maintenance conditions. The results for each bridge are depicted in Figure 5, where the x-axis represents age (operating time), the y-axis shows the obtained maintenance index, and the ball's diameter indicates the deviation from the predicted deterioration for each bridge. This deviation reflects the difference between the calculated health index and the initially predicted health index, excluding health and reliability modifiers.

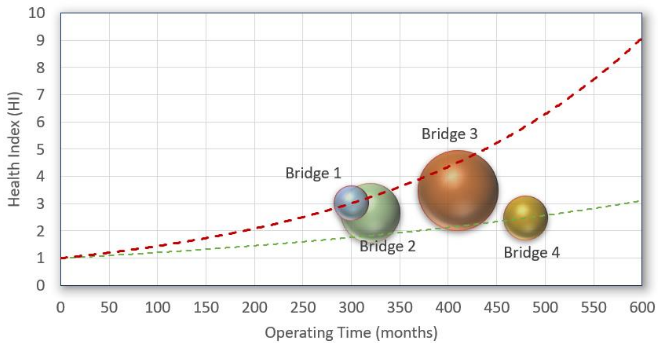

Figure 5. AHI versus age projection. Representation of current health index versus the initially estimated for bridge age.

It is observed that Bridge 1 has the most unfavorable health index, even though it has the least number of operating hours. Despite this, as indicated by the ball diameter, this aging rate aligns quite closely with what was expected, unlike Bridge 3, which, with higher age, was expected to have a more favorable health status. This could be attributed to:

- Experiencing worse operating and/or maintenance conditions than initially planned, such as increased heavy vehicle traffic beyond the initial consideration or exposure to more adverse weather conditions than those anticipated in the bridge design. To determine these causes, data mining or establishing KPIs will be necessary to identify the reasons for these deviations in the health index.
- The calculated health index does not align with the actual health status of the bridge, and therefore, recalibrating the model based on the knowledge of expert personnel from the installation will be necessary.

3. CONCLUSIONS

This research delves into the crucial facets of maintenance digitization, acknowledging the existing gap in its effective implementation despite the strides in IoT platforms and digital twin technologies. The proposed framework not only aligns with the creation of the Asset Administration Shell (AAS) and its digital twin but also underscores a model-centric approach to asset and maintenance management in the digitization process.

The research acknowledges the challenges posed by infrastructure assets lacking historical monitoring records and proposes a solution enabling the integration of monitoring variables with the characterization of technical aspects affecting comprehensive asset health degradation. The model's adaptability allows for refinement based on actual degradation processes, encouraging meticulous recording and interpretation of significant data and events.

The limitations of the proposed methodology will depend on the availability of information about the physical assets, specific knowledge about their behavior, and the ability to accurately approximate their health status. However, the flexibility of the model will allow for easy recalibration and adjustment of the asset health calculation, enabling representation through successive adjustments until replicating expert knowledge about the physical asset is achieved.

In summary, this study furnishes a framework for the effective digitization of maintenance, emphasizing practical implementation, model-based perspectives, and the strategic integration of an asset health index model, ultimately contributing to the advancement of digitization practices in the realm of maintenance management.

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DATA INTEGRATION OF PLANT EQUIPMENT'S AND SPARE PARTS AND IMPACT OF THAT ON THE COST COMPUTING IN THE SEAWATER DESALINATION SECTOR

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Abstract
The purpose of this paper is to discuss the method of data integration between the AKZ numbering and classification system; "Plant Equipment Coding", and MESC; Material and Equipment Standard Code, for spare parts. The new results achieved is more cost computing accuracy and precision. In conclusion, there two method; method one for existing plant and method two for new plant construction and both of the methods are important to be implemented on enterprise resource planning system in the seawater desalination sector for better cost computing precision.
Keywords: Data Integration, Plant Equipment's, Spare Parts

Acknowledgment
Full regards and appreciation to Professor Salih Duffuaa and Professor Shokri Selim from the department of Industrial Engineering in the university of King Fahad Univesity for Petroleum and Minerals for their vital contribution and support to complete this paper, towards boost the industrial sector in applying cost management and control.

1 Introduction

1.1 Brief
In order to have better control of the cost on the plant, you need to précised computing of the cost. Data integration between the equipment in the plant and its spare parts will be of much help in this. However, this is not achieved in practice due to separate system of coding. The equipment coding in the plant is following AKZ numbering and classification system, whereas, the spare parts coding is following MESC material and equipment standard code.

1.2 Problem Definition
There are two methods; method one is for the existing plants, and method two is for the new plants construction, and both of the methods are important to be implemented on enterprise resource planning system in the seawater desalination sector for better cost computing precision.

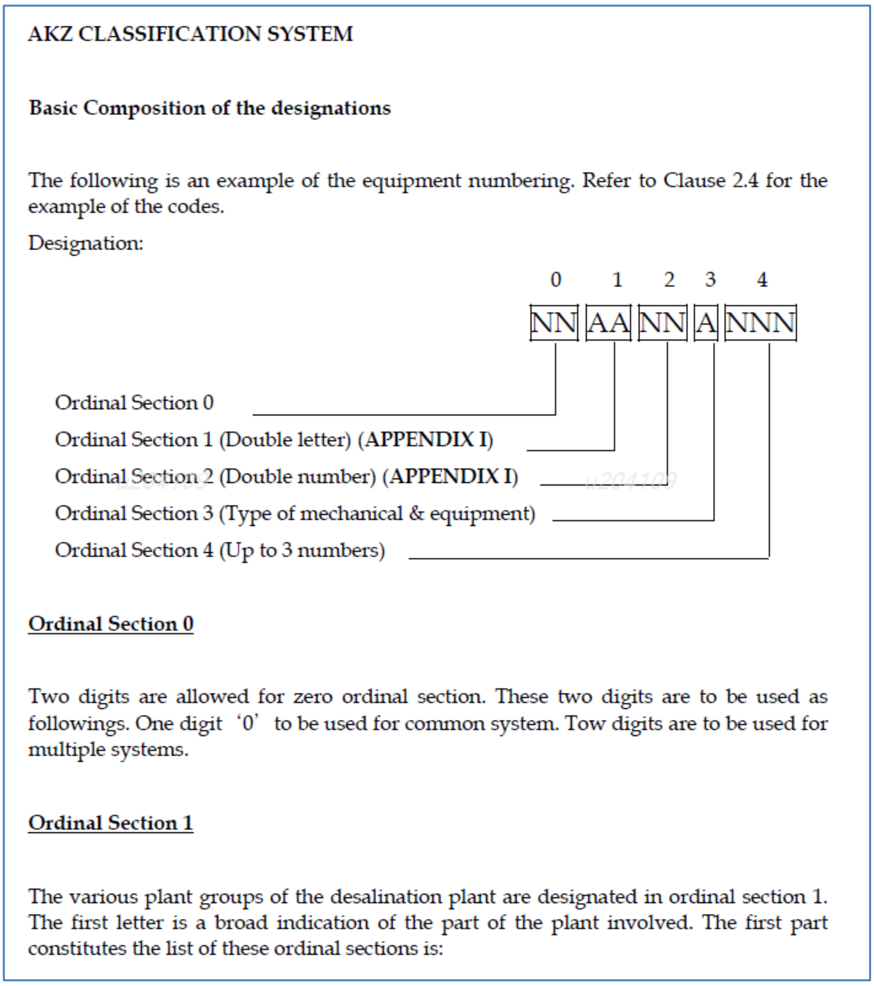
1.3 Objective
The purpose of this paper is to discuss the method of data integration between the AKZ numbering and classification system; "Plant Equipment Coding", and MESC; Material and Equipment Standard Code, for spare parts

1.4 Proposed Solution
The suggested method is to do data normalization for existing data to have a system of data integration for new data when constructing a new plant.

1.5 Alternative
Many IT company have tried many methods to fix this problem but it was not having a remarkable achievement due to the complexity of the data integration of the existing data and at the end relied on the experience of the employee who is working on the plant.

1.6 Evaluation
The new results will be achieved is more cost computing accuracy and precision due to the data link between the equipment and the spares in the plant.

2 Background



AKZ CLASSIFICATION SYSTEM

Basic Composition of the designations

The following is an example of the equipment numbering. Refer to Clause 2.4 for the example of the codes.

Designation:

Ordinal Section 0

Two digits are allowed for zero ordinal section. These two digits are to be used as followings. One digit '0' to be used for common system. Tow digits are to be used for multiple systems.

Ordinal Section 1

The various plant groups of the desalination plant are designated in ordinal section 1. The first letter is a broad indication of the part of the plant involved. The first part constitutes the list of these ordinal sections is:

Figure 1 AKZ Classification System [3].

The plant designation system AKZ is a predecessor system for identifying plants, systems, sub-systems, and equipment items for plant operating companies. The implementation of AKZ is formalized by commonly known regulations. The system categorization identifies entire machinery in a plant, from the smallest electronic component to the largest turbo-alternator. It also covers the buildings and structures. equipment is broken down into a number of levels. nomenclature structure.

The MESC – Material and Equipment Standards and Code, is the cumulative development from idea born on October 1932, when it was recognized that a system was required whereby materials from various manufacturers and countries specified to different national standards, could be readily compared, identified and administrated. Moreover, national standards did not exist for many articles used by the companies and own standards had to be established to ensure safe and efficient operations. These were the basic ideas on which the concept of the MESC was based [1].

MESC comprises three kinds of document:

The "CODING SCHDULE"; which provide the common framework for coding of any item used in the company. It specifies the relevant group sub-group and/or sub-sub-group, viz.: the first 4 or 6 figure of a ten-figure code number.

The "CATALOGUE"; which show buying descriptions, units of measure and illustrations of selected materials and equipment together with their ten-figure code numbers.
The "GENERAL INDEX TO MESC"; which is a list, in alphabetical sequence, all materials and equipment recorded in the "Coding Schedule" and "Catalogue" and refer to the first 4 or 6 figures of the ten-figure code numbers.

The "General Index to MESC" is developed by SHELL INTERNATIONALE PETROLEUM MAATSCHAPPIJ B.V. [1]

3 Methodology

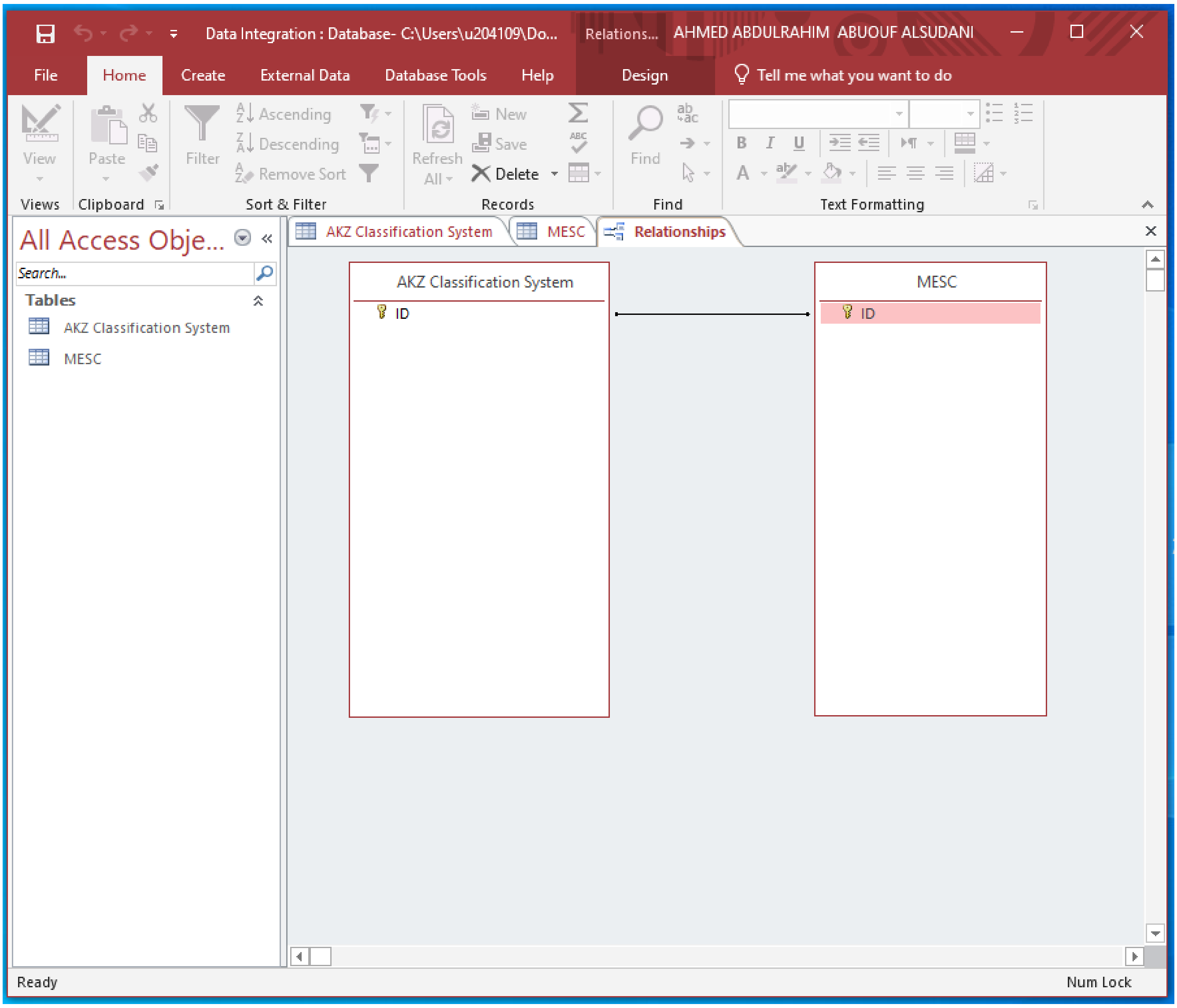


Figure 2 Data Integration of AKZ Classification System with the MESC and One-to-One Database Relationship

First of all, the idea of integrating plant equipment's coding system to its crossponding material and spare parts, it looks simple from the first looking point, however, when you go into practice and to the deep details of the process, it looks not easy. From Information Technology point of view; it is only mater of establishing One-to-One database relationship. However, the table primary key's of the AKZ classification system is different from the table primary key's of the MESC. Thus, you endup with many-to-many database relationship instead of One-to-One database relationship. Next, we do have two types of plants; (1) existing plants and (2) new plants. For every type we need to establish a method of creating database relationship between its AKZ System and its MESC System. Then, for the newplant, we need to track the database relation creation from the early stage of the plant creation project. Whereas, for the existing plant, practicly, it is done through the maintenance and operation people experience to establish the database relationship with the help of the IT people. This is done through, the maintenance people start to code the spare parts of the equipment by the time when the plant is in operation. In Fact, there is a real need to establish a standard policy and procedure to qurantee early database relationship establishment.

At the beging, we need a system that track and document the creation of the plant from its early stage; asset-by-asset. Also, nowadays, there are many companies for building Enterprise Resource Project such as Oracle and SAP had succeeded in developing ERP systems that cover many aspects of the investment projects. Then, Which all covers the life cycle of the assets and could suite the implementation of Data Integration. In Conclusion, Enterprise Asset Management enables the customer to Support compliance and corporate governance with an enterprise perspective.

4 Discussion

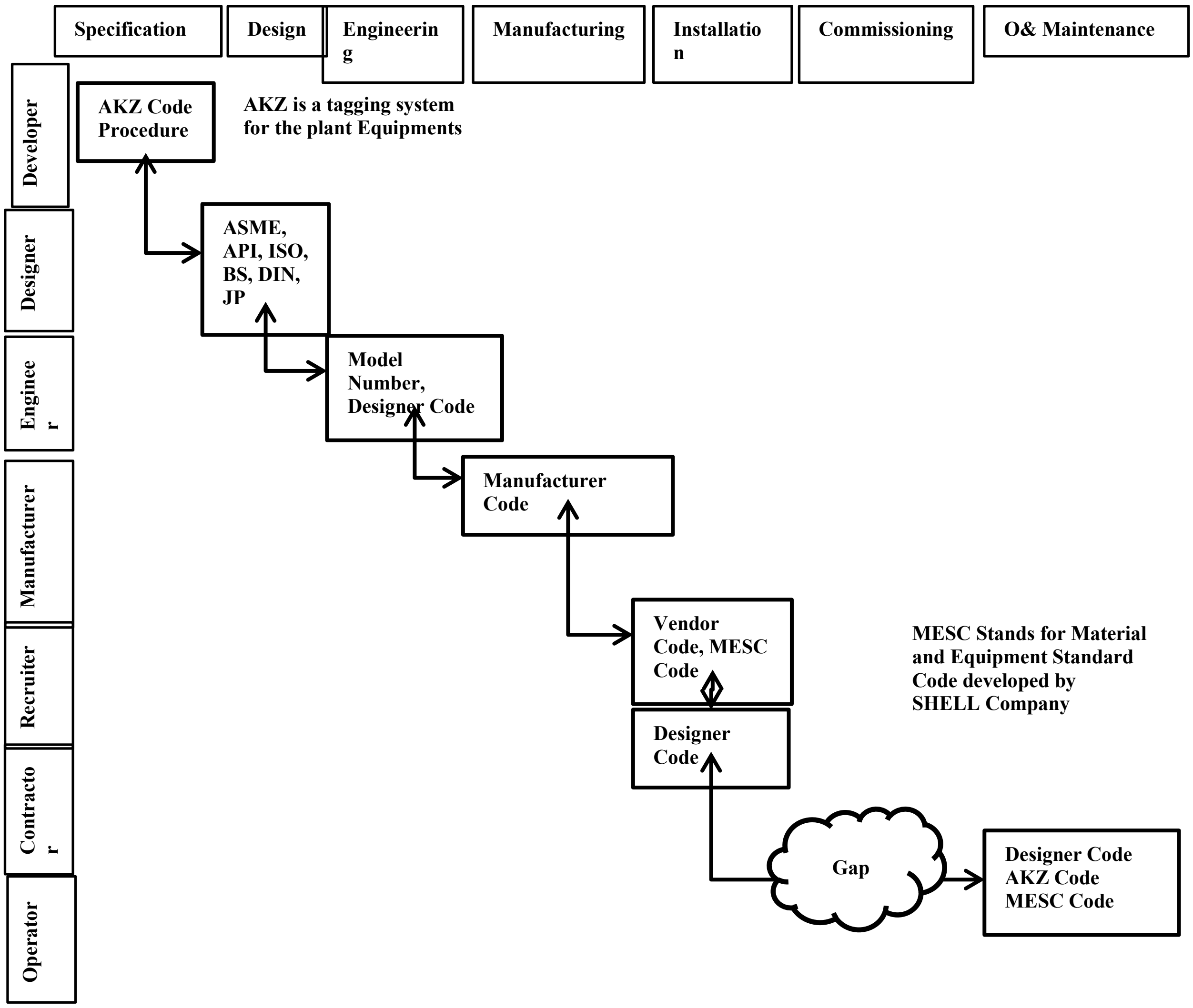


Figure 3: Asset Creation Process through the Stages of the PPP (BOOT) Plant Creation [2].

At the beging, the plant operator should co-operate with the designer/manufacturer/installer in a full analysis of its reliability, maintainability and safety characteristics. Such a 'plant procurement' exercise should include assessment of spare-part provisioning, of maintenance personnel training and of supplier support systems. The higher the potential costs of maintenance and unavailability the more vital is this exercise. Also, Decisions to buy new or replacement equipment should be based on a present-value life-cycle analysis of costs. Such an analysis must take into consideration both maintenance and unavailability costs — these being estimated, wherever possible, from documented experience. Then, The plant operator and supplier should co-operate in the collection and analysis of plant failure and maintenance data in order to identify maintenance problem areas and to determine the plant's optimum maintenance operation. Since the design of equipment is a continuing process, information thus gathered should, ideally, be continuously fed back to the equipment manufacturer, and in certain circumstances to a data bank, which could be shared on an intercompany, national or international basis. The difficulties of these last operations continue to pose a major obstacle to the successful implementation of a data integration approach, communication systems are expensive and different organizations (with different objectives) are involved during the equipment life cycle [4]. In Conclusion, we need a system that track and document the creation of the plant from its early stage; asset-by-asset.

5 Results

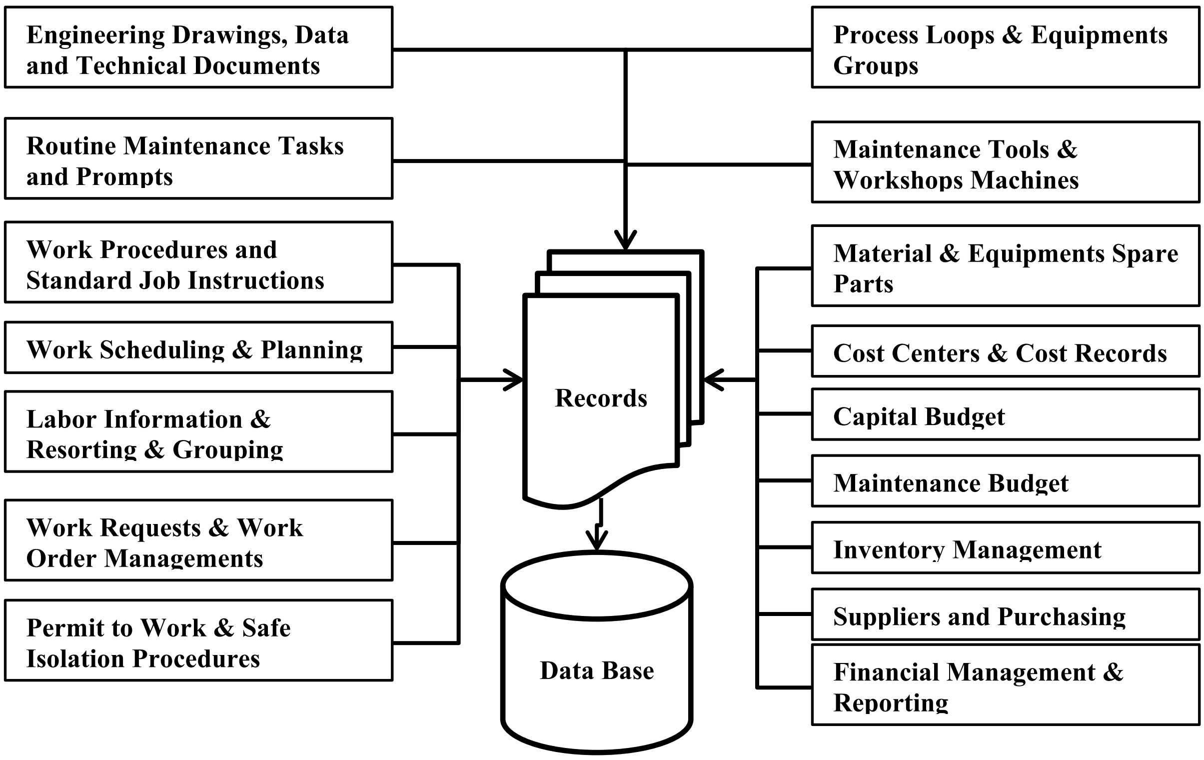


Figure 9: The Role of Enterprise Resource Planning Systems in the ease of Data Integration [2].

At the beging, there two methods for applying cost accounting; one, applying cost accounting on your process, two, applying cost accounting on your activities. Also, the more you apply cost accounting on your system, the more accurate and precise your results. Then, the vital of data integration between your plant equipment’s coding system and the spare parts and materials coding system of the plant. In addition, from quality control point of view, in order to control and identify the losses in your plant process and activity , you need to track the higher part of your plant that is producing failures in system. In Conclusion, having a system of data integration between the AKZ Classification System and the MESC is must not a luxury.

6 Conclusions

In order to have better control of the cost on the plant, you need to précised computing of the cost. Data integration between the equipment in the plant and its spare parts will be of much help in this. However, this is not achieved in practice due to separate system of coding. The equipment coding in the plant is following AKZ numbering and classification system, whereas, the spare parts coding is following MESC material and equipment standard code. There are two methods; method one is for the existing plants, and method two is for the new plants construction, and both of the methods are important to be implemented on enterprise resource planning system in the seawater desalination sector for better cost computing precision.

The purpose of this paper is to discuss the method of data integration between the AKZ numbering and classification system; "Plant Equipment Coding", and MESC; Material and Equipment Standard Code, for spare parts. The suggested method is to do data normalization for existing data to have a system of data integration for new data when constructing a new plant. Many IT company have tried many methods to fix this problem but it was not having a remarkable achievement due to the complexity of the data integration of the existing data and at the end relied on the experience of the employee who is working on the plant. The new results will be achieved is more cost computing accuracy and precision due to the data link between the equipment and the spares in the plant.

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Cost Optimal Asset Replacement Plan – Case study

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Abstract
This article describes a case study of application of decision model when setting up plan for renewal of assets. This particular case is dedicated to material handling equipment (AGV) while the principle is applicable for any type of asset. The first part of the article shows project situation and premises. The second part describes used methodology for project solution. In the third part the methodology is applied and the project results are presented. The article is finished by conclusion of the project as well as evaluation of usage of the methodology.

Keywords: asset management, asset renewal, replacement cycle, asset lifecycle costing, cascading decision making

1 Situation

In the plant the company operates a fleet of 418 units of AGV (Automated Guided Vehicle). The fleet consists of groups of different generations of technology and ages between 3 and 12 years. Due to technological development the plant is facing situation where availability of spare parts for older generations is not further guaranteed by suppliers.

Given the problem described - ongoing technological developments and the operational aging of the fleet, it is necessary to set up a systematic approach, starting with preparation of a Plan for conceptual renewal of the fleet. The Plan is result of comparison of possible scenarios for asset replacement in terms of minimal costs and other criteria when applicable.

Number of AGV unites:	418 pcs
Types of AGV:	12
Planning horizon:	10 years
Interest rate:	9%
Considered costs:	Renewal costs (AGV unit price)
	Flat rate maintenance service (prev. + correct. maintenance, operation)
	Overhauls
	Spare parts
	Re-certification and upgrades of current AGV types
	Purchase of batteries

Before start of any action, it is essential for all project "stakeholders" to understand and confirm **"Why"** it is done (so called the Purpose or "Higher Goal" of the project). In this case it is **Ensuring stable operation of driverless handling equipment that meets the needs of logistics and production processes** and **Optimization of costs of driverless handling equipment.**

In compliance with the project Purposes the detailed project goals are set. The difference between those two is that project goals have to be done within the project scope and outputs has to be delivered in accordance. The project goals are:

Phase I: Collection and **Analysis of input data**

Phase II: Definition of **Replacement Scenarios** of the fleet

Phase III: Comparing scenarios and drawing up an optimal **Replacement Plan**

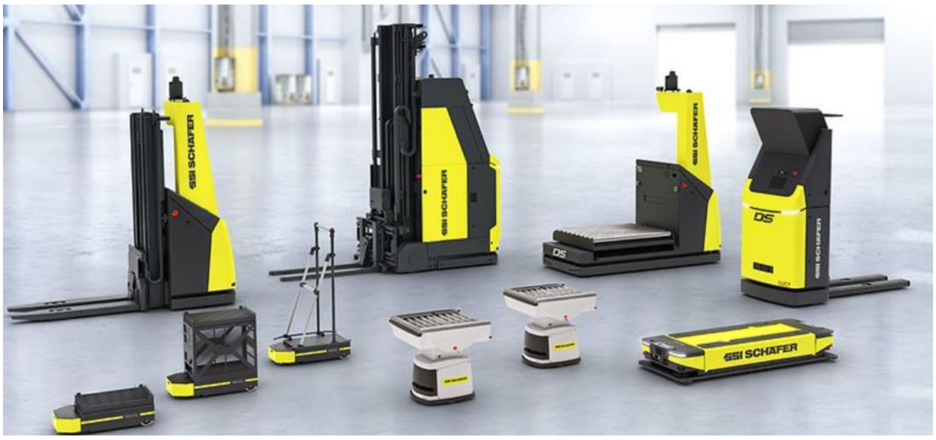


Figure 1: Illustration of AGV handling equipment (source: SSI SCHAFER)

2 Necessary cooperation within the company

A vital condition for project success is preparation of input data in a correct extent and structure. The key data requirements are as follows:

- A list of individual FTS units with Unique Identifier (the identifier must also be included in all subsequent data sets in order to assign the AGV unit to the data), including information for each unit:
  - Place of operation (hall/route)
  - Date of entry into service or, where applicable, date of manufacturing
  - Shift regime of operation
  - Type of ownership (own, leasing with maintenance, full-service, etc.)
- Mileage km and moto-hours from commissioning to present by months
- History of maintenance performed on individual AGV units with a description, labour consumption, materials and maintenance costs from the time of commissioning to the present
- List of charging stations with the assignment of AGV operating groups
- Consumption of energy, oils/other operating media for individual AGV from the time of commissioning to the present
- List of critical parts for which the support ends incl. term and BOMs
- List of offered used / retrofitted AGV from partners incl. price and technical condition
- Electricity costs for charging at individual charging stations
- Cost of CAPEX + estimation of price indexation and residual value (including costs of acquisition and commissioning, disposal of old equipment, administration, etc.)
- OPEX costs + estimation of cost development for individual AGV units monthly from commissioning to the present
- Other relevant costs (if any)
- Discount rate for calculating the NPV of the future cash flow

3 Project Methodology

In this chanter the key steps to set up Replacement plan are described. As the project constrains and premises always vary, the solution is always individual according to situation (asset type, extent and quality of input data, key user/decision maker preferences, etc.)

The key attributes to establish Replacement plan are validated replacement criteria and rules. By setting prioritization and sequence of criteria the cascading decision tree is made to create Replacement scenarios. Replacement criteria of the case are shown in Table 1.

Table 1: Replacement criteria and rules

No.	Criterion	Description
1	**Replacement Model**	Optimal replacement cycle - the local minimum function of the total average annual costs. **If there is no local minimum, the replacement cycle is 8 years (according to the information from manufacturer).**
2	**End of Spare parts (SP) support**	The lifespan can be extended (the year of replacement shifted) by cannibalization of other units or by re-certification of missing part. AGV will never be replaced before the end of SP support defined by manufacturer/dealer.
3	**AGV Cannibalization**	**Principle:** the lifespan of a certain group of AGV is extended at the expense of other AGV units, which are put out of service, and from which SP are cannibalized. **Cannibalization parameters:** on the basis of SP historical consumption, the future consumption of SP for lifetime extension of AGV kept in service is determined. And finally, the number of discarded (renewed) AGV units is calculated and as well as extended life of the remaining AGV.
4	**Re-certification (upgrade)**	Some types of AGV can be upgraded – the critical spare part is replaced by newer model and type of AGV is upgraded so that SP unavailability is eliminated. The CAPEX for upgrade and extended lifespan of the particular AGV type is set by manufacturer.
5	**Overhauls**	According to the manufacturer, Overhaul is carried out every 4 years of operation of a unit. The second option is implementation of Overhaul based on the difficulty of the route where AGV is operated. The year of replacement is shifted by certain number of years from the last performed Overhaul, which prevents replacement of unit where significant cost to Overhaul was recently invested.
5	**Routes**	Some AGV types cannot be replaced individually, the replacement has to be done by the whole group in one time.
6	**Cost of AGV per km/hour of operation**	Types of AGV are evaluated in terms of cost depending on mileage and shift regime. AGV with higher costs are then, replaced as a priority within the concept of cannibalization or within the route.
7	**Technology update**	The current concept does not consider a change of technology from AGV to AMR, as well as the transition from lead-acid to lithium-ion batteries due to the returnability of investment.
9	**CAPEX limit and distribution**	The limit of CAPEX is not set. Requirement of the plant is to distribute CAPEX evenly over the years.
10	**Limit for Overhauls**	Yearly limit for number of performed Overhauls and related costs is defined.
11	**Capacity of manufacturer**	Maximal production of 500-700 unites of AGV yearly is defined.

3.1 DATA ANALYSIS

Clearing of data, segmentation of the fleet (age, mileage, costs), investigation of corelation of costs with age/mileage, AGV type, place of operation etc. Structure and quality of the data reflects future constrains and deviations of results. Results should be always presented together with this information.

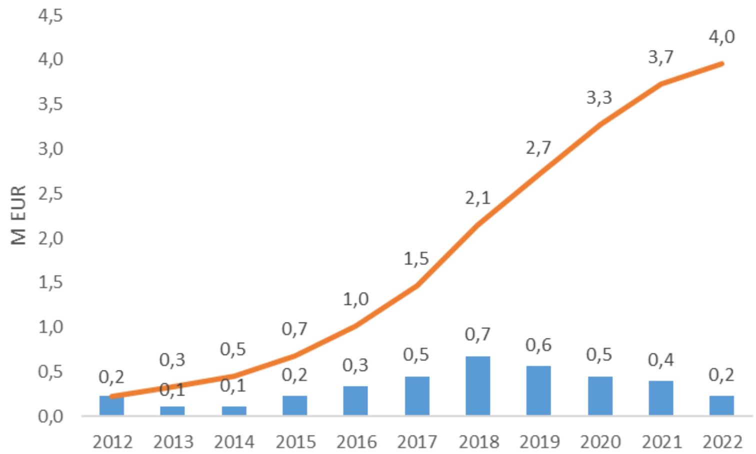
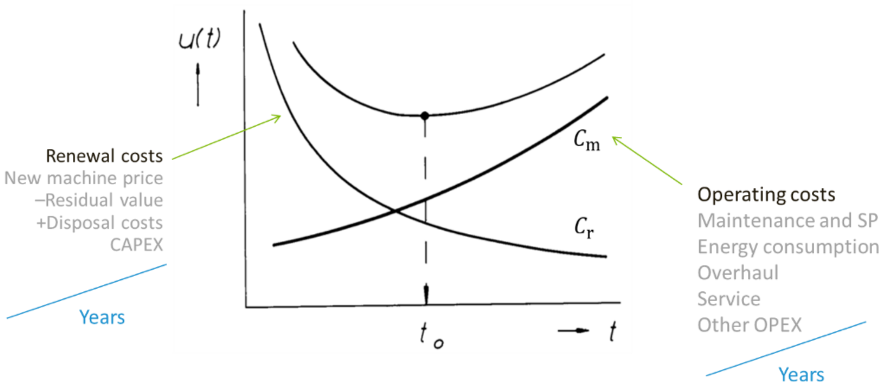


Figure 2: OPEX development by years

3.2 REPLACEMENT COST MODEL

Searching for cost optimum of the replacement interval. For every single AGV unit the minimum average annual cost of ownership is analysed.



$$u(t) = \frac{C_r(t) + C_m(t)}{t} = \frac{C_r(t)}{t} + \frac{C_m(t)}{t}$$

Figure 3: Replacement cost model calculation

3.3 REPLACEMENT SCENARIOS

The defined replacement criteria are reflected in the cascading decision tree. The result is single year of replacement for each unit, not yet containing all the constrains and mainly not yet taking into account the corporate processes for replacing assets (technological, economic and administrative constraints).

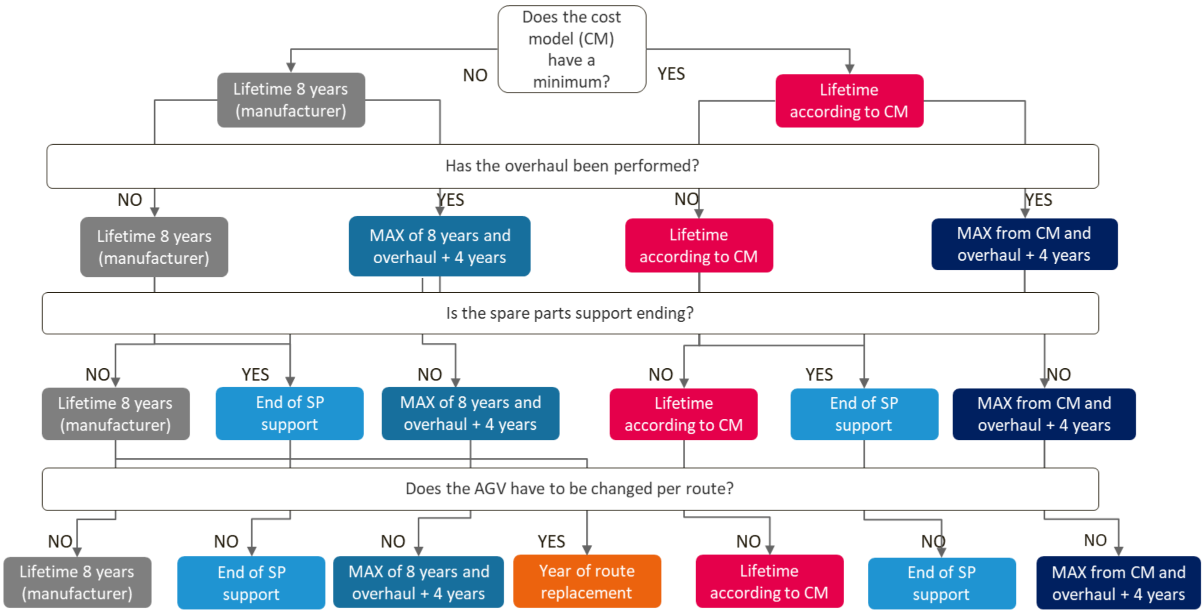


Figure 4: Cascading decision tree

3.4 REPLACEMENT PLAN

Replacement plan is factual replacement schedule based on all constrains. Cannibalization and re-certification are also only incorporated at this point for its non-standardized approach that would bring an enormous complexity when used in phase of establishment of Replacement scenarios.

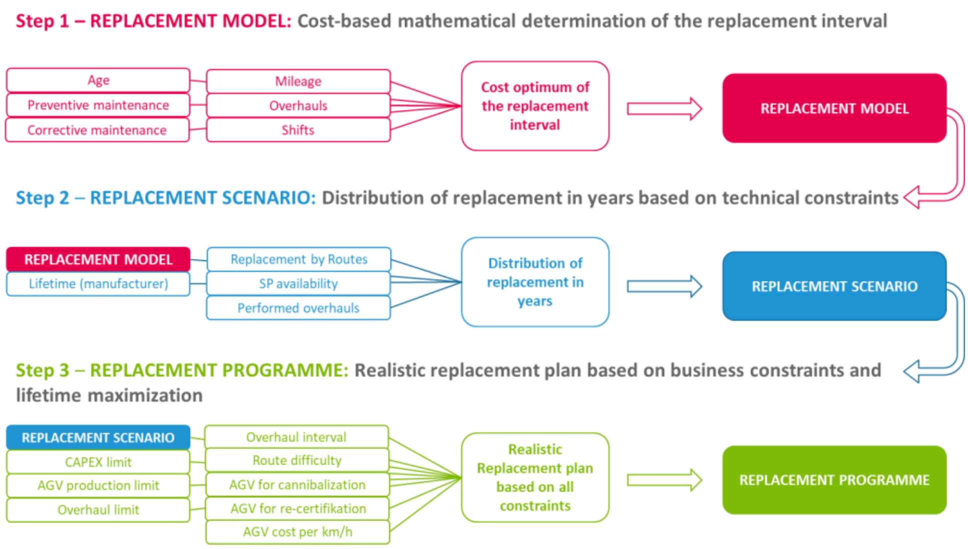


Figure 5: Three steps for determination of Replacement plan

4 Project results

The final Replacement plan is based on mathematical determination of the replacement year + application of cannibalization of spare parts (longer AGV life-time and optimized CAPEX), optimization of AGV replacement distribution in years (CAPEX optimization), optimized recertifications and upgrades (levelling-out CAPEX for recertification) and optimized number of overhauls in years (levelling-out CAPEX and capacities for overhauls).

Other principles applied within the establishment of the Replacement plan are:

As result of data analysis the cost optimum of 8 years of AGV lifetime given by the manufacturer was verified. AGV with the highest cost per km/h of operation and on the most demanding routes is replaced first.

If the AGV is close to the planned replacement, the overhaul is not performed. If an overhaul has been performed, the lifetime of the AGV is automatically extended by 4 years.

The utilization of maintenance capacity, new AGV production capacity and annual CAPEX spendings are maximized.

Each AGV is kept in operation until the end of SP support. The lifetime of AGV is extended by obtaining SP from decommissioned AGV or by upgrading SP with ending support.

Main Result: Longer average lifetime of AGV unit (+3 years). Thanks to the systematic approach around 10 M EUR less will be paid in total costs in the given time horizon.

Example of graphical outputs of the project are seen on Figures below.

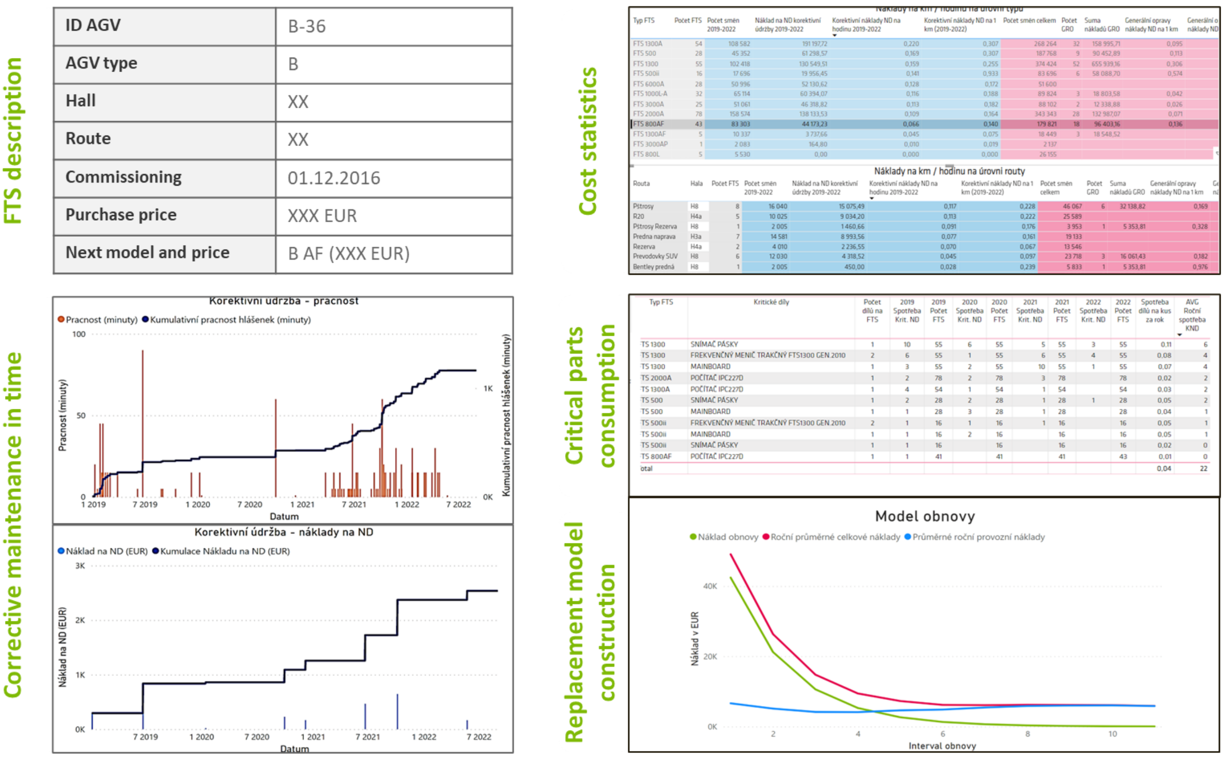


Figure 6: Complex costs analysis and segmentation for single AGV unit

AGV Type	1	2	3	4	5	6	7	8	9	10	11	12	Total
A	1		2		33								36
B							1	1	40	6	3	11	62
C					26			5	31				61
D						2	2	1					6
E					42	17	2	27					88
F			8			16	2	2					28
G			1										1
H									9	6	7	10	32
I								1	1	1	2	12	18
J		8	24										32
K	2			2	29	1	5	9					49
L				6									6
	3	8	35	8	130	36	12	46	80	12	12	34	418

The oldest types must be replaced by route

Newest FTS

End of SP availability 112 units

Figure 7: Segmentation of the AGV fleet by age

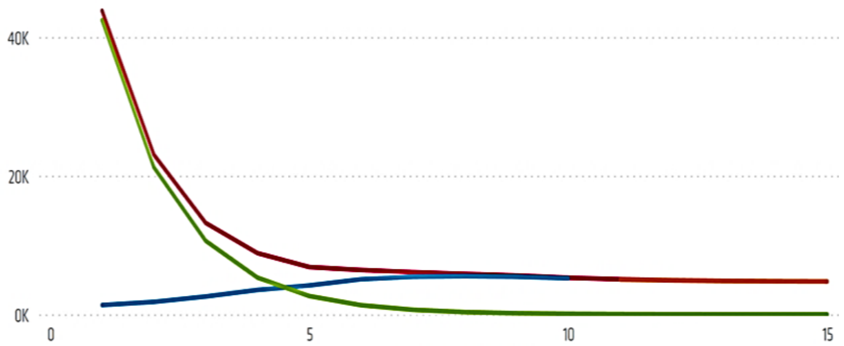


Figure 8: Example of Cost Replacement model without minimum annual average costs – it does not show progressivity over time, and it is close to linearity. For this reason, the annual average cost curve (red) has no local minimum. The optimum in this case is to replace the AGV unit never and to continue preventive and corrective maintenance until total obsolescence.

AGV Type	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	Total
A						36						36
B	44			18								62
C									51			51
D									10			10
E								61				61
F									6			6
G									19	60	9	88
H											28	28
I						1						1
J	7			25								32
K	10			8								18
L							32					32
M											49	49
N								6				6
	61	0	0	51	0	37	32	67	86	60	86	479

Figure 8: Number of replaced units of AGV in years

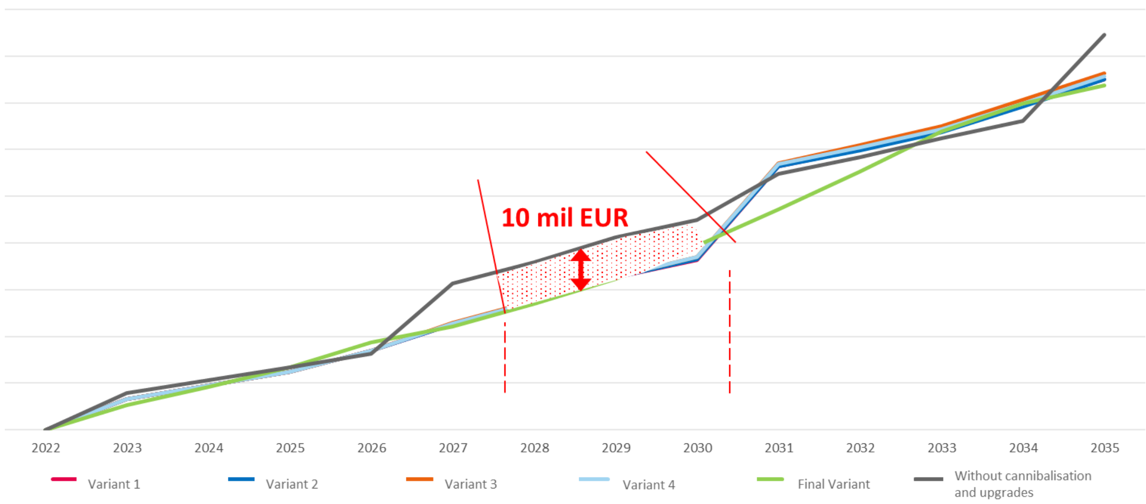


Figure 8: Distribution of cumulative CAPEX + OPEX in years

5 Conclusion

Based on the course of the project, it can be stated with certainty that when managing a large number of assets, such as a fleet, it is hardly imaginable to achieve any optimal solution for asset replacement without a systematic approach and a data-based solution.

On the other hand, the data-based solutions have pitfalls indeed and poor data quality can be critically misleading. Therefore, it is necessary to evaluate how a given shortage of data can contribute to the overall result. The typical data pitfalls of such projects are missing cost history, missing links of costs to individual asset units (group payments and flat rates under framework contracts), work orders missing causes of repairs and used spare parts, data is not consistent – duplicates, missing connection between data sources through unique identifiers. The flat rates and framework contracts can cause misleading information for a cost model that does not show the progressivity of maintenance costs with age and thus the average annual cost function has no local minimum. Based on experience, the data requests must be submitted in advance and in clearly defined structure and extent. The responsible person has to be appointed to hand the data over on time and to be ready for subsequent consultation and explanation of the data as it is never done on the first iteration.

Another challenge may be indexing costs in the future, especially in economically unstable times, when for longer planning horizons, the deviations can cause significant differences in total costs or a change in the order of variants for decision-making.

The methodology of creating a Replacement Plan has proven its robustness in adapting to the conditions and requirements of the individual cases. When there are validated and cleaned data, the Cost model is appropriate base to get understanding of asset replacement cycle. The final realistic Replacement plan is then completed by sequence of applying replacement criteria with given prioritization.

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ESG Metrics and Risk Factors in Asset and Facility Management: Adapting to Mandatory Reporting Policies

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Abstract

The growing emphasis on Environmental, Social, and Governance (ESG) considerations is profoundly reshaping how global companies manage their assets and facilities, especially in light of impending mandatory reporting requirements. This study critically examines key ESG metrics and risk factors relevant to asset and facility management across various industries worldwide. Through a comprehensive analysis of existing literature and reports, it identifies prevalent ESG challenges and evaluates their impact on operational efficiency and corporate responsibility. The findings underscore the increasing necessity for standardized ESG frameworks that incorporate risk management strategies to meet evolving reporting obligations and stakeholder expectations. The study presents actionable recommendations to enhance the integration of ESG principles in asset and facility management, fostering sustainable operations, improving transparency, and ensuring compliance with emerging global standards. Additionally, the study analyzes secondary data from Saudi-listed companies, providing insights into how corporate governance mechanisms such as board independence and audit committee composition influence ESG disclosures. These findings contribute to the ongoing discourse on sustainable corporate governance, highlighting ESG's role in mitigating risks and bolstering long-term organizational resilience.

Keywords: Economic diversification, ESG reporting, Sustainable Development Goals (SDGs), Corporate social responsibility (CSR), Environmental, Social, and Governance (ESG), Asset Management, Facility Management.

1 Introduction

ESG (Environmental, Social, and Governance) is a framework for evaluating how businesses manage sustainability, social responsibility, and corporate governance. It is important for assets because it ensures long-term value and resilience against risks like climate change. For employees, ESG promotes fair labor practices, diversity, and safety, leading to a healthier work environment. Companies benefit from ESG by improving reputation, attracting investors, and fostering sustainable growth. On a global scale, ESG drives positive impacts on the world by addressing environmental challenges, promoting social equity, and encouraging ethical governance.

Integrating Environmental, Social, and Governance (ESG) considerations has become a critical aspect of corporate strategy, significantly influencing how companies manage their assets and facilities. There has been a growing emphasis on sustainability and responsible management practices in recent years, driven by increasing regulatory requirements and stakeholder expectations [1]. Companies are now expected to demonstrate their commitment to sustainable operations through internal policies, transparent reporting, and adherence to emerging global standards [2].

Mandatory ESG reporting requirements are becoming more prevalent worldwide, compelling organizations to adopt standardized frameworks for evaluating and disclosing their sustainability performance [3]. These frameworks, such as the Global Reporting Initiative (GRI) and the Sustainability Accounting Standards Board (SASB), guide companies in measuring and reporting key ESG metrics, enabling them to communicate their efforts effectively [3]. However, integrating these principles into asset and facility management poses unique challenges, including balancing operational efficiency with environmental stewardship and social responsibility [4].

This paper examines the key ESG metrics and risk factors pertinent to asset and facility management across various industries globally. Through a comprehensive analysis of existing literature and reports, the research seeks to identify prevalent ESG challenges and evaluate their impact on operational efficiency and corporate responsibility. The findings will underscore the increasing necessity for standardized ESG frameworks incorporating risk management strategies to meet evolving reporting obligations and stakeholder expectations. The significance of the paper is that it has the potential to offer actionable recommendations for enhancing the integration of ESG principles in asset and facility management. This integration is crucial for adopting sustainable operations, improving transparency, and ensuring compliance with emerging global standards [5]. Through a comprehensive analysis of current sustainability practices and their impact on operational efficiency, this paper contributes to the ongoing discourse on sustainable corporate governance, highlighting the role of ESG in mitigating risks and bolstering long-term organizational resilience.

2 Literature Review

2.1 ESG in Asset and Facility Management

Integrating Environmental, Social, and Governance (ESG) considerations into asset and facility management has garnered significant attention in recent years, primarily due to its impact on operational efficiency, risk management, and long-term sustainability [6]. ESG integration in this context involves a holistic approach to managing assets and facilities that accounts for environmental impacts, social responsibilities, and governance practices. Research has shown that organizations adopting ESG-focused asset and facility management strategies are better positioned to address emerging regulatory requirements and stakeholder expectations [7].

One key aspect of ESG integration in asset management is adopting sustainable practices, such as energy-efficient building designs, renewable energy sources, and water conservation measures [8]. These practices reduce the environmental footprint and contribute to cost savings and improved asset value over time. Similarly, social considerations, such as ensuring safe and healthy working conditions and engaging with local communities, have been linked to enhanced corporate reputation and employee satisfaction [9].

2.2 Mandatory Reporting Requirements

Globally, there is a growing movement towards mandatory ESG reporting, with various countries and regions implementing regulations that require companies to disclose their sustainability practices [10]. For example, the European Union's Corporate Sustainability Reporting Directive (CSRD) mandates that companies provide detailed information on their ESG initiatives, including their environmental and societal impact [10]. In the United States, the Securities and Exchange Commission (SEC) also considers rule changes requiring ESG disclosures, emphasizing transparency and accountability [11]. Figure 1 shows the percentage of companies in the Middle East that have certain types of sustainability reporting. More than 50% of the companies in the Middle East have no stand-alone sustainability report.

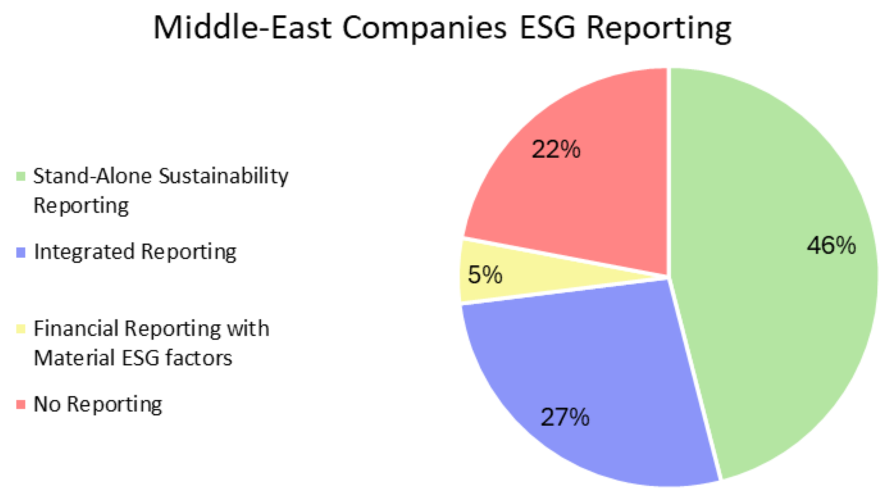

Figure 1 Distribution of ESG Reporting Practices in the GCC Region [12]

These mandatory reporting requirements have significant implications for asset and facility management. Companies must implement sustainable practices and develop mechanisms for tracking and reporting their ESG performance [13]. This has led to the adoption of standardized reporting frameworks, such as the Global Reporting Initiative (GRI) and the Sustainability Accounting Standards Board (SASB), which provide guidelines for measuring and communicating ESG metrics [3, 14].

While integrating ESG principles into asset and facility management offers numerous benefits, it also presents challenges. One of the primary challenges is balancing operational efficiency with sustainability goals [6]. Implementing energy-efficient systems, for example, may require significant upfront investment, which can be a barrier for some organizations. Additionally, a lack of standardized ESG metrics and reporting practices makes it difficult for companies to benchmark their performance and demonstrate their commitment to sustainability [15].

Despite these challenges, integrating ESG principles presents opportunities for organizations to enhance their long-term resilience and competitiveness [8]. By adopting a proactive approach to ESG, companies can mitigate risks, improve stakeholder relations, and access new markets and investment opportunities. Moreover, consumers' and investors' growing demand for sustainable practices incentivizes companies to integrate ESG into their asset and facility management strategies [9].

3 ESG Supports SDG Implementation

- Aligning Business Strategies: By adopting ESG principles, companies ensure their operations are aligned with the SDGs, integrating sustainability into their business models and fostering long-term positive impacts on society and the environment.
- Financial Sustainability: Many financial institutions and investors are aligning their portfolios with the SDGs, using ESG criteria as a tool to invest in sustainable business practices that contribute to the goals.
- Corporate Responsibility: ESG provides a framework for companies to demonstrate corporate responsibility, which goes hand in hand with achieving the SDGs, ensuring businesses actively contribute to solving global challenges.

Summary Table of ESG and SDGs Relationship:

ESG Dimension	Related SDGs	Key Areas of Focus
Environmental	SDG 7, 12, 13, 14, 15	Energy efficiency, climate action, sustainable resource use, biodiversity, pollution reduction.
Social	SDG 1, 3, 4, 5, 8, 10, 11	Health & safety, labor rights, gender equality, education, diversity, inclusion, decent work, urban development.
Governance	SDG 16, 17	Anti-corruption, transparency, partnerships, strong institutions, ethical governance.

So, ESG is a practical approach that aligns business operations with the broader global framework of the SDGs. By adopting ESG principles, companies contribute to the achievement of the SDGs through sustainable practices, ethical governance, and social responsibility. It bridges the gap between corporate actions and global development goals, promoting long-term sustainability and shared value creation for both businesses and society.

4 Key ESG Metrics and Risk Factors

Key ESG Metrics and Risk Factors include environmental, social, and governance aspects. Environmental metrics cover energy efficiency and emissions, reducing the ecological footprint. Social metrics focus on health, safety, and diversity, enhancing company reputation and employee satisfaction. Governance metrics involve leadership practices, ethics, and compliance, ensuring transparency and accountability. These metrics collectively assess an organization's sustainability and risk management. Figure 2 shows the main three pillars of ESG metrics.

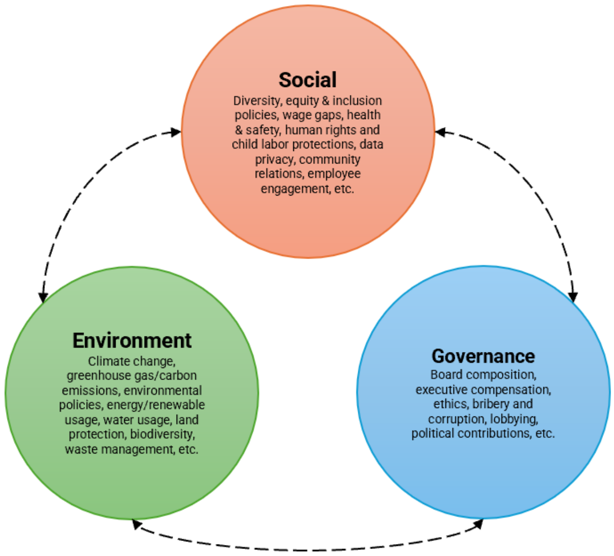

Figure 2 ESG's three main pillars are environment, social, and governance.

4.1 Environmental Metrics

Environmental metrics are central to ESG considerations, as they directly address an organization's impact on the planet. In asset and facility management, these metrics often include energy efficiency, water usage, waste management, carbon emissions, and resource conservation [15]. Companies increasingly focus on energy-efficient designs and use renewable energy sources to reduce their carbon footprint and operational costs [8]. Waste management practices, such as recycling and reducing hazardous materials, also contribute to a company's environmental sustainability profile.

Vital environmental metrics commonly used in reporting include:

- **Energy Consumption:** Measures an organization's total energy, often expressed in kilowatt-hours (kWh) or joules. The goal is to reduce energy consumption through efficient practices and renewable energy sources [3].
- **Greenhouse Gas (GHG) Emissions:** Assesses the volume of emissions produced by a company, including CO2 and other greenhouse gases. Metrics like the Carbon Intensity (CI) and Scope 1, 2, and 3 emissions are commonly used to track a company's impact on climate change [16].
- **Water Usage:** Evaluates total water consumption and aims to implement water conservation, recycling, and wastewater reduction strategies [17].
- **Waste Management:** Involves tracking the amount and types of waste generated, focusing on reducing, reusing, and recycling materials to minimize environmental impact [18].

4.2 Social Metrics

Social metrics focus on an organization's impact on its employees, customers, and the broader community. These metrics in asset and facility management include health and safety, employee well-being, community engagement, and diversity and inclusion [9]. Companies prioritizing these areas often experience enhanced reputation, employee satisfaction, and customer loyalty.

Standard social metrics include:

- **Health and Safety:** Measures the effectiveness of health and safety policies and practices in the workplace, including the frequency of workplace accidents and the provision of a safe working environment [9].
- **Employee Well-being:** Assesses job satisfaction, work-life balance, and access to training and development opportunities. These metrics are linked to employee retention, productivity, and morale [17].
- **Community Engagement:** Evaluate the company's involvement in community initiatives, philanthropy, and the impact of its operations on local communities. This includes supporting social causes and fostering positive relationships with stakeholders [19].
- **Diversity and Inclusion:** Tracks the representation and inclusion of diverse groups within the organization. Metrics include gender and ethnic diversity in the workforce, leadership positions, and policies promoting an inclusive work environment [20].

4.3 Governance Metrics

Governance metrics are critical to assessing a company's leadership, ethical practices, and adherence to regulatory requirements. In asset and facility management, strong governance ensures that ESG initiatives are effectively integrated into corporate strategies and operations [7]. These metrics include board diversity, executive compensation, anti-corruption measures, and stakeholder engagement.

Key governance metrics include:

- **Board Diversity:** Evaluates the composition of the board of directors regarding gender, ethnicity, and expertise, promoting diverse perspectives in decision-making [21].
- **Executive Compensation:** Assesses how executive pay is linked to the company's performance and ESG goals, ensuring alignment with long-term shareholder interests [22].
- **Anti-Corruption and Ethics:** Measures the effectiveness of policies and practices to prevent corruption, bribery, and unethical behavior within the organization [23].
- **Stakeholder Engagement:** Tracks the company’s efforts to communicate with and involve stakeholders in its decision-making processes, ensuring transparency and accountability [24].

5 Overview of ESG Performance and Corporate Governance in Asset and Facility Management

The study involves reviewing and analysing ESG performance reports from various companies across different industries. These sources include publicly available sustainability reports, ESG ratings from third-party agencies, and company disclosures aligned with frameworks such as the Global Reporting Initiative (GRI) and the Sustainability Accounting Standards Board (SASB) [3, 14]. The reports were gathered from established databases like Bloomberg, Refinitiv, and MSCI, in addition to company websites and sustainability reports [3, 15].

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A purposive sampling method was employed to select companies that have publicly disclosed their ESG performance and have a significant presence in asset and facility management. The sample includes companies from various industries, including real estate, manufacturing, and energy, providing a broad perspective on ESG practices [7]. The study identifies key ESG metrics relevant to asset and facility management based on their prevalence in the literature and industry practices. These metrics include energy consumption, greenhouse gas emissions, water usage, waste management, health and safety records, and board diversity [15, 16, 18].

A review of existing literature and reported ESG metrics were performed to identify patterns, trends, and potential correlations between ESG performance and aspects like operational efficiency, financial performance, and risk management. This review draws on statistical analyses presented in the sources to provide an overview of ESG practices across the sampled industries [7, 8].

The review of ESG performance reports across various industries reveals considerable differences in how companies integrate ESG practices into their asset and facility management. Industries like real estate and manufacturing have shown significant strides in adopting energy-efficient building designs, renewable energy usage, and waste management practices [15]. For example, firms implementing green building standards such as LEED certification have experienced noticeable reductions in energy consumption and greenhouse gas emissions, thereby improving overall operational efficiency [2, 15].

In the social domain, numerous companies have established health and safety protocols that include regular training sessions, emergency preparedness programs, and wellness initiatives aimed at enhancing employee well-being [9, 19]. These practices have been linked to reduced incident rates and improved employee satisfaction. Additionally, community outreach programs have been employed by some organizations, helping them build a strong social license to operate and fostering positive stakeholder relationships [19].

Despite these advancements, integrating governance metrics remains less common among companies. Metrics such as board diversity and executive compensation linked to ESG performance are not as prevalent [21, 22]. Although some organizations

have adopted anti-corruption measures and transparent stakeholder engagement practices, there is a general lack of emphasis on governance within asset and facility management contexts.

The review suggests a positive relationship between ESG performance and operational efficiency. Companies that prioritize environmental metrics like energy consumption and waste management often report lower operational costs and enhanced asset value over time [8]. Investments in sustainable technologies and designs lead to reduced utility expenses and maintenance costs, resulting in higher profit margins [16]. Social initiatives, such as health and safety programs, also correlate with increased productivity and reduced absenteeism [9], while enhancing corporate reputation and customer loyalty [19].

However, the quantifiable impact of governance practices on operational efficiency remains less clear and requires further investigation. While essential for ethical conduct and regulatory compliance, governance metrics' direct influence on tangible operational outcomes is less evident [7, 22].

The study identifies several challenges in the integration of ESG practices into asset and facility management. A primary challenge is the significant upfront investment required for sustainable technologies and infrastructure [6, 8]. Even though such investments yield long-term benefits, initial costs can be prohibitive, particularly for smaller organizations. Furthermore, the lack of standardized ESG metrics and reporting practices complicates efforts to benchmark performance and communicate sustainability commitments [13].

Risk management is a critical aspect of ESG integration. Companies with robust ESG strategies are generally better equipped to mitigate risks associated with regulatory compliance, environmental liabilities, and social conflicts [22]. Proactively addressing environmental risks like resource scarcity and climate change can improve an organization's adaptability to regulatory changes and market shifts [16]. Engaging in stakeholder dialogues and community engagement initiatives is crucial for managing social risks and maintaining a company's social license to operate [9].

This analysis underscores the pressing need for standardized ESG frameworks that integrate risk management strategies and facilitate compliance with evolving reporting obligations [3, 14]. Adopting standardized reporting practices, such as those outlined by the Global Reporting Initiative (GRI) and the Sustainability Accounting Standards Board (SASB), can help companies better communicate their ESG efforts to stakeholders and align with global sustainability goals [3, 15]. However, existing frameworks have gaps, particularly in the context of asset and facility management governance practices [23]. There is a need for industry-specific guidelines that address the unique challenges and opportunities in integrating ESG considerations into this field.

6 ESG Integration in Saudi Arabia: A Review of Practices and Implications

An in-depth review was conducted on integrating ESG principles in Saudi Arabia's corporate sector. This analysis focused on understanding the strategies employed by key companies, such as Saudi Aramco and SABIC, and their challenges and best practices in implementing ESG initiatives. The study highlighted how these companies align with global ESG standards and address region-specific sustainability challenges. It also examined Saudi Arabia's national strategies, like the Saudi Green Initiative, to provide context on how government policies support and drive corporate ESG efforts [25].

Saudi Arabia has been making significant strides in integrating ESG practices within its corporate sector, aligning with the nation's Vision 2030 and sustainability goals. The Saudi Stock Exchange (Tadawul) has issued ESG Disclosure Guidelines to promote transparency and encourage companies to report on their environmental, social, and governance practices. Additionally, Tadawul launched an ESG index to promote further and track the ESG performance of listed companies, fostering a culture of sustainability and corporate responsibility in the country [25].

6.1 Key ESG Initiatives in Saudi Arabia

1. **ESG Integration Across Companies:** A recent PwC survey shows over 60% of Saudi Arabian companies have embedded ESG issues into their business strategies. This significant shift demonstrates a commitment to sustainability, showing how companies increasingly align their operations with global expectations for responsible business conduct [25].

2. **Investment in Sustainability Initiatives:** The Saudi Green Initiative encompasses over 60 sustainability initiatives, with an investment surpassing SR700 billion (around $186.6 billion). These projects aim to increase the use of clean energy, offset emissions, and address climate change, reflecting the nation's strong focus on environmental sustainability as part of its economic development strategy.

3. **Corporate Emissions Reduction Targets:**

   - **Saudi Aramco:** One of the largest oil companies globally, Saudi Aramco provides annual metrics on its environmental impact, including data on water consumption, hydrocarbon spillage, sulfur oxide emissions, and carbon emissions. This transparency reflects the company's commitment to reducing its environmental footprint and maintaining operational excellence.

   - **SABIC (Saudi Basic Industries Corporation):** SABIC has committed to making all its operations carbon neutral by 2050. The company focuses on renewable and circular feedstock, demonstrating a shift towards more sustainable production processes. This move illustrates the industry's efforts to contribute to a greener future in a region traditionally dominated by oil and gas.

4. **Green Financing:** Saudi Arabia's Public Investment Fund (PIF) has embraced green financing by issuing bonds totaling $5.5 billion. This initiative shows the Kingdom's commitment to funding sustainable development through innovative financial instruments, indicating a growing interest in green financing as a vital tool for promoting environmental sustainability.

5. **Challenges in ESG Implementation:** Despite the progress, several challenges persist. Approximately 40% of regional companies cite a lack of internal skills and expertise as a significant obstacle to implementing ESG initiatives. Additionally, one-third of companies reported ESG funding constraints as a significant barrier, highlighting the need for further investment in training programs and financial support to facilitate ESG integration.

6.2 Implications for Asset and Facility Management

The review of Saudi Arabia's practices exemplifies how companies in the region increasingly integrate ESG principles into their operations. By aligning with global ESG standards and implementing substantial sustainability initiatives, Saudi companies are enhancing their environmental performance, improving social and governance practices, and contributing significantly to the country's overall sustainability goals. This approach serves as a model for other organizations in the

Middle East, demonstrating that ESG integration can drive long-term organizational resilience and create value for stakeholders.

6.3 Most Influential Factors on Companies' ESG Scores in Saudi Arabia

The study analyzes a dataset comprising 206 company-year observations from Saudi-listed companies from 2010 to 2019 collected in a survey carried by Bamahros et al. [26]. The dataset includes quantitative and qualitative variables that provide insights into corporate governance mechanisms and their impact on ESG disclosures. Key variables collected include:

Table 1 Description of ESG Scores, Corporate Governance Factors, and Control Variables [26]

Variable	Description
ESG Scores	A measure of a company's environmental, social, and governance performance. The scores are derived from various ESG disclosure practices and are used as the primary dependent variable in the study.
Board Size	The total number of directors on the company's board reflects the board's capacity for oversight and decision-making.
Board Independence	The proportion of independent directors on the board indicates the level of independent oversight and potential influence on ESG practices.
Audit Committee Independence	The percentage of independent members on the audit committee highlights the committee's ability to provide unbiased monitoring of ESG reporting.
Audit Committee Meetings	The frequency of meetings the audit committee holds shows the committee's engagement level in overseeing ESG disclosures.
External Audit Committee Members	A binary variable indicates the presence of external members on the audit committee, reflecting the diversity of perspectives and expertise brought to the committee.
Board Meetings	The number of board meetings indicates the board's active involvement in company oversight.
Government-owned Institutional Investors	Government-owned investors may influence the company's governance and ESG practices.

The collected data enables the study to investigate the relationships between various corporate governance mechanisms and the level of ESG disclosures, providing insights into how governance practices impact sustainability reporting. Using quantitative metrics (e.g., board size, ESG scores) and qualitative aspects (e.g., presence of external members) allows for a comprehensive analysis of the factors influencing ESG performance.

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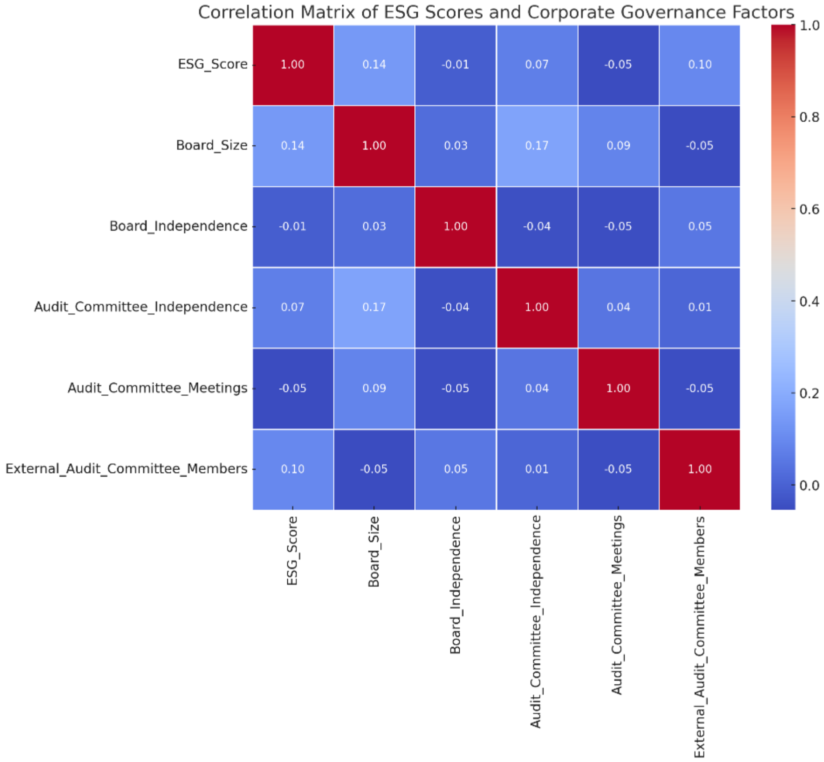

Figure 3 Correlation Matrix of ESG Scores and Corporate Governance Factors

The paper analysis reveals that specific corporate governance mechanisms significantly influence ESG disclosure among Saudi-listed companies. A strong positive correlation was found between the independence of the audit committee and ESG scores, indicating that companies with a higher proportion of independent members on their audit committees tend to have more comprehensive and transparent ESG reporting. This suggests that independent audit committees are crucial in ensuring rigorous ESG disclosures. Additionally, external members on the audit committee are positively associated with ESG performance, highlighting the value of diverse perspectives and specialized expertise in enhancing the quality of ESG reporting. A moderate positive relationship was also observed between board independence and ESG scores, underscoring the importance of having independent directors who can provide effective oversight and promote accountable governance practices. While board size and the frequency of audit committee meetings showed positive correlations with ESG scores, their impact was less pronounced. These findings suggest that companies should prioritize strengthening audit committee independence, incorporating external expertise, and promoting board independence to improve ESG disclosures. By doing so, organizations can enhance transparency, foster stakeholder trust, and better align with global sustainability standards.

7 Recommendations and Future Studies

This study contributes to the ongoing discourse on sustainable corporate governance by providing a structured evaluation of ESG implementation in asset and facility management. It underscores the importance of integrating ESG principles for compliance and as a strategic tool for risk mitigation, operational efficiency, and long-term organizational resilience.

1. **Development of Standardized ESG Frameworks:** There is a pressing need to develop industry-specific standardized ESG frameworks to integrate ESG principles in asset and facility management. These frameworks should offer clear metrics and benchmarks, particularly for governance practices currently underrepresented in existing standards [3, 14]. A standardized approach would enhance comparability across companies and industries, making it easier for stakeholders to assess and benchmark ESG performance.

2. **Investment in Sustainable Technologies:** Companies should invest in sustainable technologies and infrastructure, such as energy-efficient systems and renewable energy sources. While the initial investment may be significant, the long-term benefits include cost savings, enhanced asset value, and a reduced environmental

footprint [8, 16]. Organizations should also explore financial incentives and subsidies for green technologies to offset upfront costs.

3. **Enhanced ESG Reporting and Transparency:** Transparent ESG reporting is crucial for building stakeholder trust and meeting regulatory requirements. Companies should adopt established reporting frameworks like the Global Reporting Initiative (GRI) and the Sustainability Accounting Standards Board (SASB) to ensure consistent and comprehensive disclosure of their ESG performance [3, 14]. Regular stakeholder engagement is also recommended to communicate ESG initiatives and address concerns, strengthening the company's social license to operate [9].

4. **Incorporating ESG into Corporate Strategy:** Organizations should integrate ESG considerations into their core corporate strategies and decision-making processes. This includes linking executive compensation to ESG performance to ensure accountability and alignment with long-term sustainability goals [22]. By embedding ESG principles into corporate culture and strategy, companies can drive sustainable value creation and enhance their resilience to emerging risks.

5. **Fostering a Culture of Continuous Improvement:** ESG integration is an ongoing process requiring continuous improvement. Companies should regularly review and update their ESG strategies in response to evolving regulations, stakeholder expectations, and industry best practices [12, 23]. Implementing internal audits and assessments can help organizations identify areas for improvement and track progress toward their sustainability goals.

6. **Incorporating Insights from the Saudi Context:** The study of Saudi-listed companies revealed that certain governance mechanisms, such as having independent audit committees and external members on the audit committee, positively influence ESG disclosures. Companies in similar contexts should consider strengthening the independence of their audit committees and including external experts to enhance the quality of ESG reporting. Additionally, focusing on increasing board independence can contribute to better oversight and improved ESG performance.

8 Conclusion

The growing emphasis on Environmental, Social, and Governance (ESG) considerations fundamentally reshapes how global companies manage their assets and facilities. This study has critically examined key ESG metrics and risk factors relevant to asset and facility management, highlighting the importance of integrating these principles into corporate strategies to foster sustainable operations and mitigate risks.

The findings reveal that while companies have made considerable progress in implementing environmental and social practices, the integration of governance within asset and facility management remains an area for improvement. Challenges such as the initial investment in sustainable technologies and the absence of standardized reporting practices hinder effective ESG implementation. However, organizations have notable opportunities to enhance operational efficiency, reduce risks, and improve corporate reputation through proactive ESG integration [8, 15].

Specific to the context of Saudi Arabia, the study observed that specific governance mechanisms, such as the independence of audit committees and the inclusion of external audit committee members, positively impact ESG disclosures. This underscores the importance of robust governance practices in enhancing transparency and accountability within the region's companies.

To address these challenges, the paper recommends developing standardized ESG frameworks tailored to asset and facility management, investing in sustainable technologies, enhancing ESG reporting and transparency, and incorporating ESG into corporate strategy. By adopting a holistic and strategic approach to ESG integration, companies can comply with emerging regulatory requirements, create long-term value for their stakeholders, and contribute to global sustainability goals.

This paper contributes to the ongoing discourse on sustainable corporate governance by providing a structured evaluation of ESG implementation in asset and facility management, including insights from the Saudi market. It underscores the role of ESG in mitigating risks, enhancing operational efficiency, and strengthening long-term organizational resilience. Future research should continue exploring ESG practices' impact on financial performance and work towards developing clear, industry-specific benchmarks to guide organizations in their sustainability efforts.

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FOSTERING INNOVATION THROUGH LEVERAGING DISRUPTIVE TECHNOLOGIES

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1. Abstract

Innovation and technology programs are among the top priority for the success of any industry around the globe. Combining these programs addresses the key gaps that are found on the current practices where a culture of innovation, eco-system and sustainability is captivated by leveraging disruptive technologies including but not limited to generative AI, digital twin, VR …. Etc. The impact of utilizing a top to bottom approach in running a business has created a barrier in the workforce to adopt new technologies or brainstorm innovative ideas. Even with the engagement form management, leadership, allocating resources, rewards and metrics, yet, it is challenging to experience the change of culture, achieve what innovation program are designed for to gain a competitive edge. Thus, a comprehensive program was established where technology and innovation are presented in one platform. This platform is designed to showcase innovative ideas, technology projects and on-going virtual campaigns across the organization.

To improve and streamline innovative ideas, guiding principles, procedures and the recommended best practices in a concise description were provided and delivered with the help of generative AI that is impeded within the innovation and technology platform. The generative AI is a one example of combining innovation and technology to gain insight based on the organization accumulated experience which were formulated into best practices and procedures along with other suggestions received by the users directly. The ultimate goal of this program is an autonomous and structured approach to refine innovative idea management processes and make it more efficient and valuable. Key metrices were developed as a starting point and are adopted to achieve a set of goals in a value adding system to constantly improve the innovation culture with the focus on quality, scalability and impact on the organization.

Part of the key metrics are the participation rate, idea review rate, approval rate, implementation rate and innovation realized value. These metrics were the starting point to measure the effectiveness of the innovation program. However, when combined with technology deployment, more metrics are added including: technology realized value, approved technology utilization, development of technology roadmap and others. As a result, this unique innovative and technology program has paved the way toward creating the culture of innovation. In addition, it proved its credibility through a comprehensive platform equipped with the necessary tools to effectively evaluate and process innovative ideas and technologies. Moreover, it provided a dynamic guideline for improving the idea evaluation process and enhancing the implementations of innovative ideas and technology deployment companywide.

Keywords: Innovation, Technology , culture.

2. Introduction

Innovation and Technology are a top priority for all successful organization around the globe. Exploiting employee creativity within the organization is the way to stay competitive. Effectively utilizing that creativity requires a defined strategy, process and culture to fully realize the benefits. While the need for Innovation and Technology are universally accepted, not everyone knows how to create and sustain the desired innovative environment. The key elements of a successful Innovation and Technology program include: Culture and Leadership, Innovation and Technology Roadmap and framework, Metrics and Rewards.

This paper seeks to provide a concise description of the guiding principles, procedures and the recommended best practices governing innovation and technology management. The ultimate goal is a structured approach to refine selected proposals and idea management processes and make it more efficient and valuable. In addition to the establishment of a value adding approach where the main focus is on the quality of the proposals and ideas as well as their added value to the organization.

The best practices and procedures are the outcome of the organization accumulated experience that is formulated in proposals and idea management, corporate discussions among subject matter experts (SMEs) and suggestions received by the organization's employees. This paper will revolve around the process of adopting innovation and technology deployment program in oil and gas industrial setup that provides the necessary outlines to effectively evaluate and process innovative ideas and technologies submitted via a dedicated Portal. In addition to providing a guideline for improving the proposal and idea evaluation process and enhancing the implementations of innovative ideas and technology deployment across the organization.

3. Objectives

The objective of this paper is to demonstrate a comprehensive program toward adopting innovative culture and foster technology deployment in the organization with the focus on oil and gas industry. In addition to providing examples on how disruptive technologies contributes toward fostering innovation. The program is driven by multiple aspect where the following were carefully considered during the establishment and planning phase:

- Culture and leadership
- Deployment framework
- Performance measure
- Integrating disruptive technology

4. Innovation and Technology Culture and Leadership

An innovation and technology committee is formed within the organization and consist of leadership rules and SMEs to evaluate, approve and implement proposal and ideas that are submitted for the consideration by the Committee Members. The committee main role is managing ideas submitted to create value out of their implementation, and a complementary role of promoting innovation and technology deployment program.

The team responsibility is to ensure strategic alignment within the organization to meet the program objective, streamline innovation and technology deployment and maximize value realization.

Following are the key roles and responsibilities of the committee:

- Scout and identify latest trend

- Collaborate, communicate, and coordinate innovative idea demonstration and technologies for piloting, deployment and utilization and capture lesson learned
- Monitor the execution of the innovation and technology program
- Provide and retain documented information as evidence of innovation and technology evaluation forms, value realization, quotations, assessments, studies, etc
- Provide technical support to enhance and optimize innovation and technology program
- Provide progress updates related to innovation and technology adoption, deployment and utilization.
- Oversee progress, action items and Key Performance Indicators (KPI) for each of the selected innovative idea and technology

One aspect of promoting the program is through Innovation and Technology Campaigns that are focused to address organizational challenges in which several ideation sessions are conducted to build business cases and deliver a path forward to enhance current processes, improve current practices and resolve challenges. Theses campaigns target, but not limited to, the below areas of interest:

- Safety enhancement
- Process improvement
- Environmental and sustainability
- Process control and cybersecurity
- Circular economy

Collaboration plays a vital rule in the success of piloting, deploying and implementing innovation and technology proposals and ideas. Thus, Innovation and technology program must forge several external and internal collaborated with SMESs, suppliers and vendors. One benefit of the collaboration is enabling the organization to receive innovation and technology deployment success stories with high adoption potential in the relevant field.

The team responsibility is to align all deployment efforts of within the department, review and evaluate applicable innovative ideas and technologies with a focus on multiple trends including digital transformation and industrial revolution technologies (IR 4.0). The objective of the team is to streamline technologies' deployment for value realization within the department.

5. Innovation and Technology Roadmap

To enable successful Innovation and Technology Deployment a dedicated roadmap shall be developed to streamline the selection and implementation processes of innovative ideas and technologies as an enabler to attend organizational challenges and seize opportunities. The roadmap shown includes deployment framework in Figure-1, processes, challenges and opportunities, performance monitoring and training & development. For oil and gas industry, the deployment framework is developed tailored two (2) driver, ten (10) domains, twelve (12) digital tracks, three (3) strategic initiatives, six (6) enablers and four (4) processes which is focused to sustain the organization status as an energy producer and further improve the implementation of innovative ideas and state-of-art technologies.

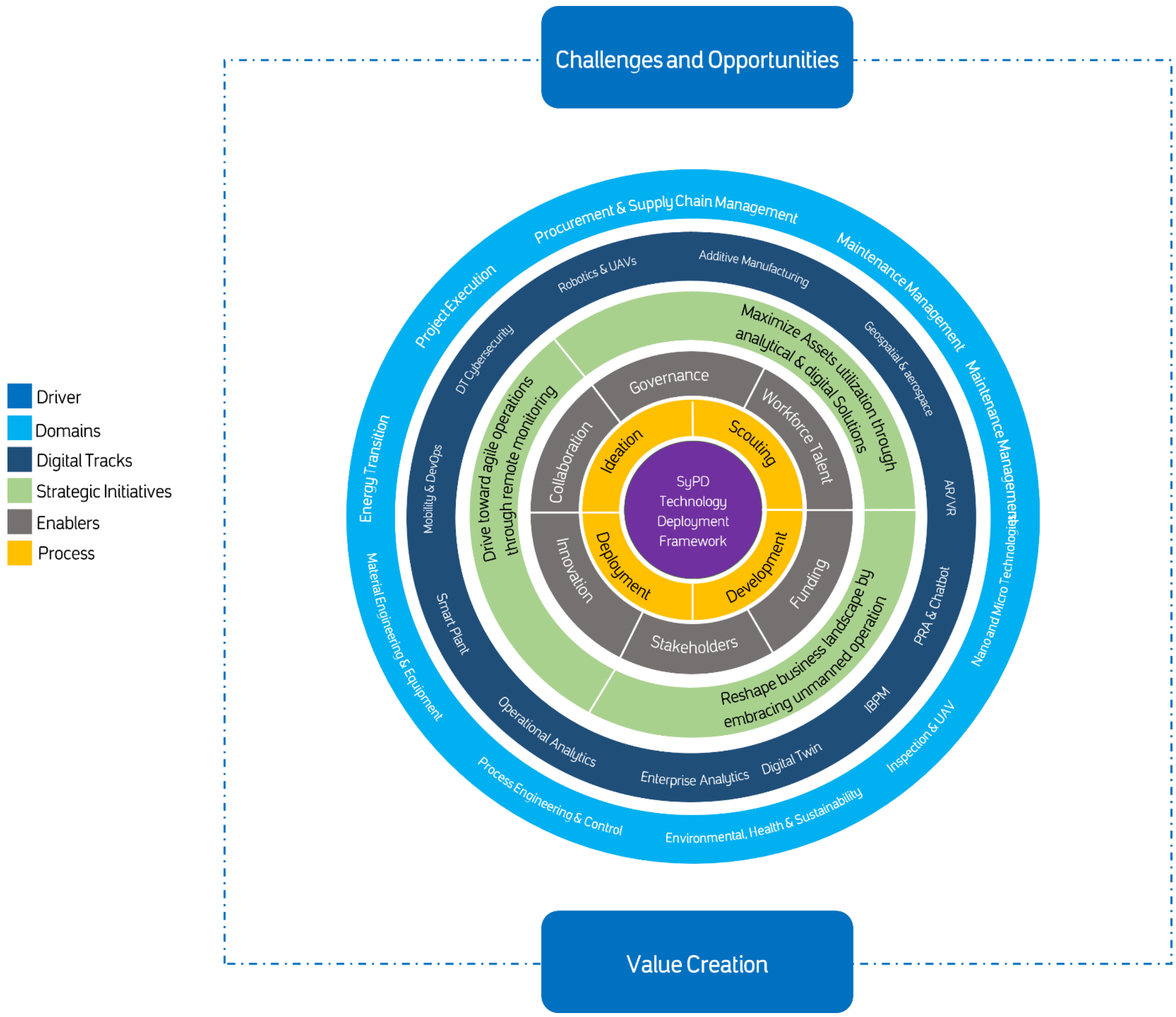

Figure 1: Innovation and Technology Framework

I. Innovation and Technology Driver

Any organization encounters significant technical and operational challenges and opportunities to produce its products at safe, cost effective, and reliable manner associated with less energy, lower emission and process improvement. An example of selected challenges based on the following attributes are shown in Figure-2:

- Value Creation
- Process improvement
- Compliance requirement
- Operational and technical challenges
- Opportunity capture

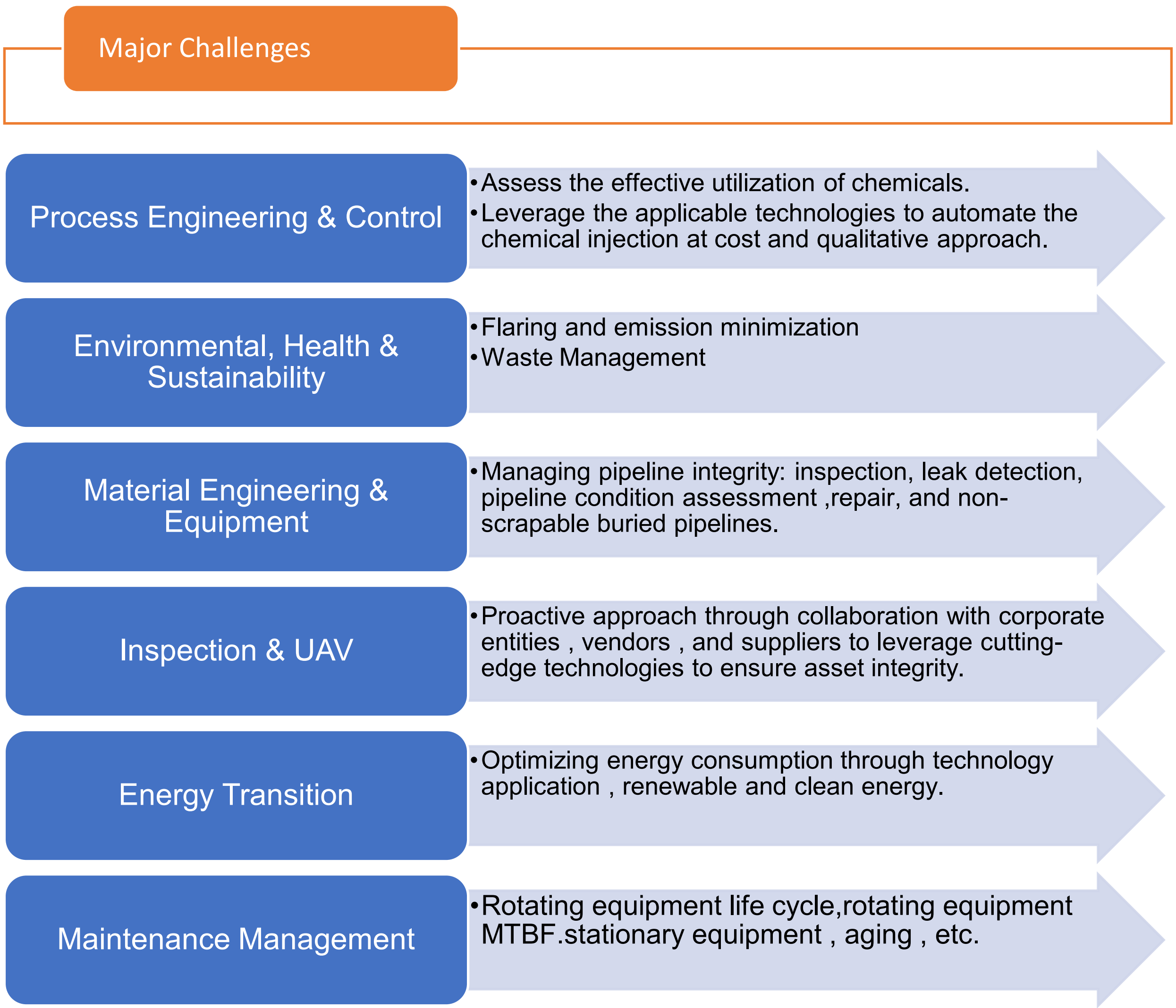

Figure 2: Example of selected challenges for an Oil and Gas producing facility

I. Innovation and Technology Domains

To streamline and focus the innovation and technology program, a set of ten (10) domains were identified which are customized for oil and gas industry mainly oil producing facilities that includes the following: Stationary Equipment, Environmental, Material & Corrosion, Electrical, Upstream Process, Non-Metallic, Energy Efficiency, Rotating Equipment, Advance Process Solution Analytics, Inspection. Any submission under the program will be classified under which domain to enabled faster process and allocate the required resources for adoption and implementation.

II. Innovation and Technology Digital Tracks

The digital tracks act as another layer of classification to streamline and focus the innovation and technology program, a set of twelve (12) tracks were identified which are customized for oil and gas industry mainly oil producing facilities that includes the following: Robotics & UAV, DT Cybersecurity, Mobility & DevOps, Smart Plant, Operational Analytics, Enterprise Analytics, Digital Twin, IBPM, RPA & Chatbot, AR / VR, Geospatial & Aerospace and Additive Manufacturing. If a submission falls under the digital track, it will have another set of SMEs for further evaluation.

III. Innovation and Technology Strategic Initiatives

The strategic initiatives act as another layer of classification to streamline and focus the innovation and technology program, a set of three (3) strategic initiatives were identified which are customized for oil and gas industry mainly oil producing facilities that includes the following: maximize assets utilization, drive toward agile operations and embrace unmanned operation. If a submission contributes to the strategic initiatives, it will have more weight and focus by the organization.

IV. Innovation and Technology Enablers

The enablers provide a framework for the innovation & technology program, a set of six (6) enablers were identified which are customized for oil and gas industry mainly oil producing facilities that includes the following: Collaboration, Governance, Workforce talent, Funding, Stakeholders. Each enabler outlines the required resources for any submission under the program.

V. Innovation and Technology Processes

Once a submission is selected, after identifying the challenges / opportunity and streamlining process that include allocating required enablers, the innovation and technology process provide a holistic overview about theses stages which includes a set of four (4) processes that were identified which are customized for oil and gas industry mainly oil producing facilities that includes the following: scouting, Identification, Evaluation, Deployment. A detailed process is illustrated below for innovative idea development along with technology deployment / adoption.

The innovation development detailed process shown in table-1 includes the following:

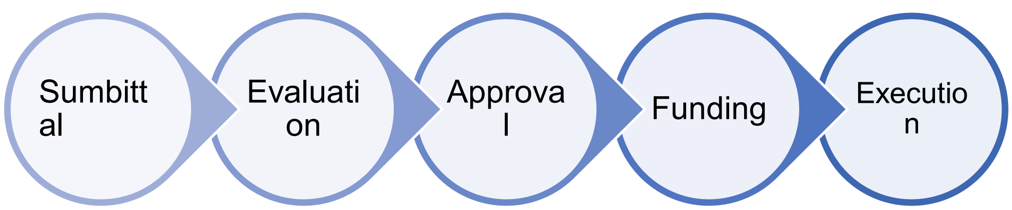

Table 1: Innovative Idea Development Lifecycle Process

ID	Process Step	Description
0	Submittal	Submittal of the innovative idea or proposal through a portal
1	Evaluation	The Innovation and technology committee along with SMEs evaluates the submittals against a pre-defined acceptance criterion
2	Approval	If the submission passed the evaluation, it is approved submittal and will be selected for implementation
3	Funding	The selected submittal for implementation, will be availed the required resources for execution
4	Execution	Once the submittal is executed, the value realization will be uploaded to the portal

The technology development detailed process shown in table-2 includes the following:

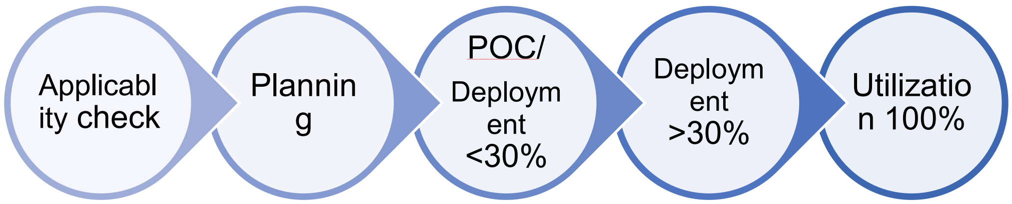

Table 2: Technology Deployment Lifecycle Process

ID	Process Step	Description
0	Applicability Check	Technology is being checked for its applicability to the operation of the organization
1	Planning	Technology is applicable and being planned for PoC or deployment
2	PoC/Deployment <30%	Technology is in PoC phase or its deployment is 30% or less of the total potential implementation locations/users
3	Deployment >30%	Technology deployment is between 30% and 100% of the total potential implementation locations/users
4	Utilization 100%	Technology deployment is 100% and it is integral part of the mainstream operation

A streamlined approach is orchestrated for evaluation and scoring where if the score is 10 or more, the idea is approved, otherwise, the idea is archived. Figure-3 shows the evaluation form:

Innovation Idea Review Form

IMC Chairman & Members:	
Idea Title:	
Evaluation Date:	

STAGE 1: Must Meet Criteria	Score	
A. Is this a genuine idea?	YES (1) ☐	NO (0) ☐
B. Can this idea improve current practice or lead to new needed services?	YES (1) ☐	NO (0) ☐
C. Is utilizing this idea practical and will add value?	YES (1) ☐	NO (0) ☐
D. Is the implementation of this idea feasible and not difficult?	YES (1) ☐	NO (0) ☐
E. Is this idea linked to COD's strategic pillars? "Motivated (Demonstrate four Critical Behaviors), Safe, Efficient, Reliable, Secure or Customer Focused"	YES (1) ☐	NO (0) ☐

Idea must meet ALL Stage 1 criteria to be considered for Approval

STAGE 2: Evaluation Criteria	Lowest		Score		Highest
F. Rate the urgency level to which this idea can overcome a challenge	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
G. Rate the degree to which this idea enhances an operation or process	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
H. Rate the degree to which this idea improves delivery of service	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
I. Rate the degree to which this idea can reduce cost and maximize value	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
J. Rate the degree to which this idea can be patentable	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐

Conclusion	
Overall Idea Score = (A*B*C*D*E) * (F+G+H+I+J)	
Archive Score < 10	Approve Score ≥ 10
Comments:	

Figure 3: Idea / proposal evaluation form

6. Innovation and Technology Metrics and Rewards

Rewards are an integral part of the innovation and technology program. Some rewards are to encourage the use of the submission portal to capture innovative ideas / technology proposals by rewarding employees who submit above a certain number of ideas / proposals. Other rewards are focused on improving the quality of ideas / proposals. It is critical to recognize exceptional performance in specific tasks that relate to innovation and technology as part of an organization's recognition program.

To measure the performance of the innovation and technology program, a set of KPIs were orchestrated as detailed in table 3.

Table 3: List of KPIs that governs the innovation and technology program

Performance Measures	Description
Employees Innovation Participation Rate (%)	(# Employees submitting Ideas) / (#Employees) X100
Innovation Excellence Index	The IEI is a composite index which measures the major components of organization's Innovation Ecosystem 0.1 * (Participation Rate (PR)/PR target) + 0.2 * (Review Rate (RR)/RR Target) + 0.1 * (Average Review Time (ART) < ART target) + 0.1 * (Approval Rate (AR)/AR Target) + 0.2 * (Implementation Rate (IR)/IR Target) + 0.3 * (Innovation Realized Value (IRV)/IRV target)
# of Filed Patents	# of Filed patents each quarter
# of Granted Patents	# of Granted patents each quarter
Technology Deployments Index (TDI)	The TDI is a composite index which measures the following components Planning: Number of Planned Technologies (%40) Execution: Percentage of Deployed Technologies (%30) Post Deployment: Value Realized from Technology Deployment (%30)

7. Fostering Innovation and Leveraging Technology

After completing all essential steps to construct an effective innovation and technology program as highlighted in previous sections, integrating technology into the innovation process plays in essential rule to excel in the implementation phase of the program. A key success that was noticed is the introduction of multiple state of the art technologies that boosted the innovation culture. The following key points will have an introduction about some the technologies and their use toward creating a culture of innovation.

I. Virtual Assistance

Virtual Assistants are transforming the way we interact with technology, providing personalized support and assistance to users across a wide range of industries and applications. By leveraging large language model, machine learning, and artificial intelligence, Virtual Assistants can understand and respond in a verity of inputs including text-based massages, enabling users to effortlessly complete tasks, access information, and manage their day to day activities. As the technology continues to advance, it is expected to see Virtual Assistants become even more sophisticated, intuitive, driving increased adoption across industries.

Integrating a dedicated virtual assistance through a chat bot application, enable employee to access on spot knowledge inquiry resolution, question answering and building expertise with the vast knowledge that any organization holds. Thus, contributing to the adoption of innovation and technology program by exploring previous submittals and success story.

II. **Robotics Process Automation**

Robotic Process Automation (RPA) is revolutionizing the way organizations approach repetitive, rule-based tasks, labor intensive from routine activities and focus the capacity for higher-value tasks that drive innovation and growth. By deploying software robots to automate tasks, RPA enables organizations to streamline processes, reduce errors, and increase productivity, while also reducing operational costs. With RPA, businesses can automate tasks across multiple systems, applications, and departments, creating a more agile and responsive organization that can adapt quickly. Moreover, RPA provides a platform for organizations to leverage artificial intelligence, machine learning, and analytics, enabling them to make data-driven decisions, identify new business opportunities, and stay ahead of the competition. As RPA continues to mature, it is inevitable to transform industries and unlock new opportunities for efficiency, effectiveness, and innovation.

A system that monitor itself and flag bad actors KPI on frequent basis through the advancement of RPA where automated performance reports are generated and sent to the concerned parties for their action. Thus, enabling leaders of the organization to overlook the performance and effectiveness of the innovation and technology program

III. **AR / VR training**

The immersive technologies of Augmented Reality (AR) and Virtual Reality (VR) are transforming the way we interact, learn, and experience the world around us. By blurring the boundaries between the physical and digital realms, AR/VR is unlocking new possibilities for education, and enterprise. With AR, users can overlay digital information onto real-world environments, enhancing everyday experiences and revolutionizing industries. Meanwhile, VR is transporting users to entirely new dimensions, enabling immersive training simulations and virtual operation demonstrations. As AR/VR technologies continue to mature, we can expect to see widespread adoption across sectors, with the potential to drive significant productivity gains, improved customer engagement, and extraordinary levels of innovation and creativity.

Taking a virtual course and then applying the thermotical knowledge into a real-world scenario has gotten much easier with the integration of AR/VR training which enabled iterative experience to be enriched through multiple scenarios where employee creativity is unlocked to come up with suggestion instead of waiting for a real scenario that act as an enhancement opportunity. Thus, enriching employee with scenarios that strike their contribution to the innovation and technology program by enabling a semi like hands on experience.

IV. **3D printing**

The advancement of 3D printing has revolutionized the manufacturing landscape, enabling the rapid creation of complex geometries and customized products with unprecedented precision and speed. By leveraging additive manufacturing techniques, organizations can significantly reduce production time, material waste, and labor costs, while also unlocking new possibilities for product design and innovation. Furthermore, 3D printing has the potential to democratize access to prototyping and production, empowering innovative ideas to created and brought to life. As the technology continues to advance, we can expect to see widespread adoption across industries, with 3D printing playing a pivotal role in driving innovation, efficiency, and sustainability in the years to come.

Prototyping is never an issue with additive manufacturing approach to swiftly fabricate and test innovative idea on the spot for new design and enabled the exploration of its limitation and flaws before the final product. Thus, enabling employee to explore ideas and effectively participate in the innovation and technology program by testing and proving their concept in the physical world.

V. **Digital twin**

The concept of Digital Twin is redefining the way we design, operate, and maintain complex systems, from industrial equipment and infrastructure to entire plant and ecosystems. By creating a virtual replica of a physical entity, Digital Twin technology enables real-time monitoring, simulation, and analysis of its performance, behavior, and potential failures. This enable predictive maintenance, optimized operations, and data-driven decision-making, resulting in significant reductions in costs, downtime, and environmental impact. In addition, Digital Twin empowers the creation of "what-if" scenarios, facilitating the testing of new ideas, and the acceleration of innovation and technology adoption. As the Digital Twin ecosystem continues to evolve, it is poised to transform industries and unlock new opportunities for sustainable growth, improved efficiency, and enhanced customer experiences.

Visualizing the internal parts without the need and hassle of lengthy dismantling process is now at hand with the use of digital twin and 3D visualization that enable the exploration of potential optimization opportunities when combined with simulation and facility historical data and performance. Thus, employee can have access to future what if scenarios and thus promoting the culture of adopting new ideas and testing new technology with minimum cost supporting the innovation and technology program.

8. Conclusion

This paper demonstrated the key aspects of a successful innovation program by combining it with technology program within the organization primarily focused on an oil and gas industrial set up and producing facilities. In addition, a unique approach is elucidated toward creating a comprehensive innovation and technology program that address current practices gaps. By creating a common platform to govern submittals with the ability of spreading awareness through virtual assistant using generative AI encapsulated in a chatbot and other means of disruptive technologies such as AR/VR, 3D printing, RPA and digital twin that drives innovation culture and business growth. Embracing cutting-edge technologies enables the organization to unlock new opportunities for value creation, sustainability, operation efficiency and competitiveness.

In summary, the below ten (10) main takeaway from the paper where disruptive technologies have the potential to drive the innovation culture are as follow:

1. **Leadership and vision**: The adoption of disruptive technology requires visionary leadership and a clear understanding of the potential risks and opportunities. Leaders need to prioritize innovation, communicate the importance of technological change, and provide direction and guidance to the team.

2. **Business alignment**: Disruptive technology often requires a cultural shift within an organization. Leaders need to foster a culture of innovation, experimentation, and continuous learning to ensure that employees are equipped to work effectively with new technologies.

3. **Fostering innovation culture**: The rapid pace of technological change requires employees to continuously update their skills and knowledge. Organizations need to invest in training and development programs that support lifelong learning and adaptability.

4. **Talent development**: Attracting and retaining talent with the necessary skills to work with disruptive technology is critical. Organizations may need to invest in training programs, and partnerships with external and internal entities.

5. **Building partnerships and collaborations**: Disruptive technology often requires collaboration with external partners, startups, and research institutions. Organizations need to develop strategies for building and maintaining these relationships to stay at the forefront of technological innovation.

6. **Strategic planning**: To successfully leverage disruptive technology, organizations need to have a clear strategy in place. This involves identifying areas where technology can add the most value, assessing potential risks and challenges, and developing a roadmap for implementation.

7. **Staying ahead of the curve**: The pace of technological change is rapid, and organizations need to be agile and adaptable to stay ahead of the competition. This involves continuously monitoring emerging trends, assessing their potential impact, and making strategic investments in new opportunities.

8. **Impact and value realization**: The adoption of disruptive technology can have far-reaching consequences, driving economic growth, and business continuity. As such, it's essential for organizations to consider the impact and value creation of their technology investments and to prioritize responsible innovation.

9. **Developing metrics for success**: Evaluating the success of disruptive technology initiatives requires new metrics and benchmarks. Organizations need to develop frameworks for measuring the impact of their technology investments on innovation, growth, and competitiveness.

10. **Utilizing disruptive technology**: Disruptive technology can bring about significant changes in how businesses operate, creating new opportunities that enabled the adoption of innovation and technology program.

As we move forward in an increasingly complex and rapidly changing business landscape, it is imperative that leaders and decision-makers prioritize innovation and technology adaptability to stay a head of the curve. By leveraging disruptive technology, organizations can have a custom based dynamic system to constantly improve and enhance the implementation process of innovative ideas and technology deployment companywide.

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THE EVOLUTION OF CONTINUES EDUCATION WITH THE FUTURE ROLE OF ARTIFICIAL INTELLIGENCE: A CASE STUDY OF UNIVERSITY OF SHARJAH

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Abstract

The continuous evolution of education is crucial in a rapidly changing world driven by technological advancements and the growing complexity of global challenges. This paper explores the transformative role of artificial intelligence (AI) in shaping the future of continuous education. By integrating AI into educational frameworks, institutions can provide personalized learning experiences, enhance accessibility, and foster lifelong learning opportunities. The study examines current trends, potential benefits, and challenges associated with AI implementation in education. It also envisions future scenarios where AI plays a pivotal role in redefining educational paradigms, ultimately contributing to a more adaptive, efficient, and inclusive educational landscape.

Keywords: Continuous Education, Community Service, Artificial Intelligence, Educational Paradigms

1 Introduction

Continuing education has long been a cornerstone of social progress, linking initial formal education with the evolving demands of the workplace and society. As society changes, the need for continuous learning and adaptation also changes. This article explores continuing education's history, status, and prospects, emphasizing its role in promoting higher education as a community service. Additionally, we delve into the thrilling future where artificial intelligence (AI) is set to revolutionize the field, strengthening and improving institutes dedicated to lifelong learning, sparking excitement and intrigue about the possibilities [1,2].

Historically, continuing education emerged as a response to the Industrial Revolution, when rapid technological progress necessitated continuous skill development. In the early twentieth century, adult education programs, evening classes, and vocational training became prevalent to equip individuals with skills needed for emerging labor markets. Recognizing their role in community service, higher education institutions have extended their offerings beyond traditional degree programs. This period saw the establishment of community colleges, extension programs, and professional development courses, making education accessible to a broader demographic. This inclusivity has welcomed working adults and non-traditional students, making them feel valued and part of a larger community [3].

Continuous education is a dynamic and integral part of the educational ecosystem today. Higher education institutions offer diverse programs, including online courses, certifications, workshops, and seminars, catering to various learning needs and schedules. The rise of online learning platforms like Coursera, edX, and Udacity has democratized access to education, allowing individuals worldwide to pursue knowledge and skills at their own pace [1]. In the context of community service, higher education institutions are increasingly partnering with local businesses, government agencies, and non-profits to design programs that address specific community needs. These initiatives often focus on upskilling and reskilling workers, promoting social inclusion, and driving economic development [4].

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2 The Future Trends and Innovations of Continues Education

The future of continuous education is poised to be shaped by several key trends and innovations [5,6]:

1. Personalized Learning: Advances in AI and data analytics enable highly personalized learning experiences. Adaptive learning systems can tailor content to individual learners' needs, preferences, and progress, enhancing engagement and effectiveness.

2. Micro-credentials and Digital Badges: The demand for shorter, more flexible learning options drives the growth of micro-credentials and digital badges. These credentials allow learners to demonstrate specific skills and competencies, making them more relevant in the fast-changing job market.

3. Collaborative learning systems: Continuing education will increasingly involve collaboration between higher education institutions, employers, and other stakeholders. Such ecosystems will ensure that educational offerings match real-world needs and provide hands-on and experiential learning opportunities.

4. Lifelong Learning Culture: Societal attitudes towards education are shifting towards a lifelong learning culture. This mindset encourages individuals to continuously seek new knowledge and skills throughout their lives, supported by accessible and flexible educational opportunities.

Figure 1 is a pie chart illustrating the key trends and innovations shaping the future of continuous education. Each segment represents a different trend with a hypothetical impact percentage.

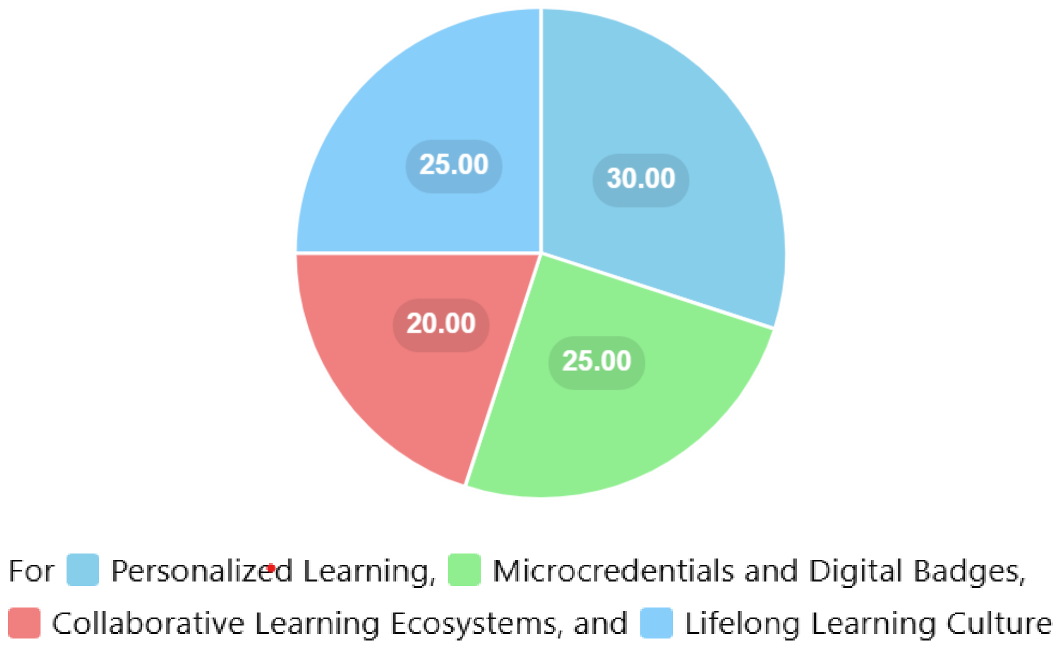

Figure 1: Hypothetical percentages for the trends and innovations shaping the future of continuous education

3 The Role of Artificial Intelligence in Continuous Education

Artificial Intelligence is set to play a transformative role in continuous education, enhancing the capabilities of institutes dedicated to lifelong learning in several ways [1,7]:

1. Personalized Learning Pathways: AI can analyze vast amounts of data to understand individual learning styles, preferences, and progress. This enables the creation of personalized learning pathways that adapt to each learner's needs, optimizing the learning experience.

2. Intelligent Tutoring Systems: AI-powered tutoring systems can provide personalized feedback, answer questions, and offer real-time guidance, replicating some of the benefits of one-on-one tutoring. These systems can support learners outside traditional classroom settings, making education more accessible.

3. Predictive Analytics: AI can predict learners' performance and identify those at risk of falling behind. This allows educators to intervene early, providing additional support to ensure all learners can succeed.

4. Enhanced Administrative Efficiency: AI can streamline administrative tasks such as enrollment, scheduling, and grading, freeing educators' time to focus on teaching and mentoring.

5. Content Creation and Curation: AI can assist in creating and curating educational content, ensuring it is up-to-date, relevant, and aligned with learners' needs. This can include generating interactive simulations, virtual labs, and personalized reading lists.

6. Skills Gap Analysis: AI can analyze labor market trends and skills demand, helping institutions design programs that address current and future workforce needs. This ensures that continuous education offerings remain relevant and valuable.

Figure 2 is a bar chart illustrating the various ways AI is set to transform continuous education. Each bar represents a different aspect of AI's impact, with hypothetical percentages indicating their relative influence.

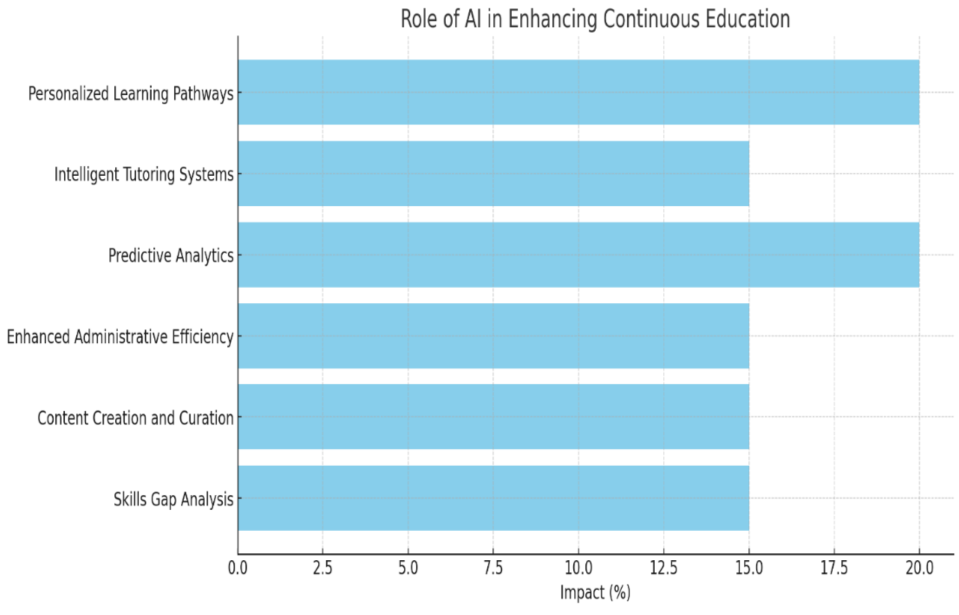

Figure 2: Various ways AI is set to transform continuous education

4 Advantages and Disadvantages of Artificial Intelligence in Continuous Education and Training

Artificial Intelligence (AI) and Machine Learning (ML) offer significant advantages and disadvantages in continuous education and community service. On the positive side, AI and ML can provide personalized learning experiences, adapting educational content to meet everyone's unique needs and learning styles. This enhances engagement and improves learning outcomes. Additionally, these technologies can automate administrative tasks, freeing educators' time to focus on teaching and student interaction. AI-driven analytics can also identify skill gaps and predict future learning needs, enabling proactive educational planning [8,9].

However, there are notable disadvantages. One primary concern is the potential for over-reliance on AI, which might lead to diminished critical thinking and problem-solving skills among learners. Additionally, AI systems can perpetuate biases in their training data, leading to unfair or inaccurate educational outcomes. There are also significant ethical and privacy considerations, as using AI involves collecting and analyzing vast amounts of personal data. Lastly, the high cost and technical expertise required to implement and maintain AI and ML systems can be a barrier for many educational institutions and community organizations.

A) Advantages in continuous education and training:

1. Personalized Learning: AI can tailor learning experiences to individual needs, preferences, and progress, enhancing engagement and effectiveness.

2. Scalability: AI-driven platforms can accommodate many learners, making education accessible to a broader audience without increasing proportional resources.

3. Real-time Feedback: AI systems can provide instant feedback and guidance, helping learners understand and correct mistakes immediately.

4. Efficiency: Automating administrative tasks such as enrollment, scheduling, and grading allows educators to focus more on teaching and mentoring.

5. Skill Gap Analysis: AI can analyze labor market trends and skills demand, helping design relevant and valuable programs for current and future workforce needs.

6. Enhanced Engagement: Interactive AI-driven tools such as simulations and virtual labs can make learning more engaging and practical.

B) Disadvantages of artificial intelligence in continuous education and training

1. High Initial Costs: Implementing AI technologies can be expensive and requires significant infrastructure, software, and training investment.

2. Data Privacy Concerns: AI involves collecting and analyzing large amounts of data, raising concerns about privacy and security.

3. Dependence on Technology: Over-reliance on AI can decrease human interaction and the development of essential interpersonal skills.

4. Potential Job Displacement: Automating administrative and teaching tasks could lead to job displacement for some educational staff.

5. Equity Issues: Access to AI technologies may not be equitable, potentially widening the gap between different socio-economic groups.

5 The Center for Continuing Education and Professional Development at University of Sharjah: A Case Study

Universities of Sharjah have long been a pillar of continuous education, extending learning opportunities beyond traditional degree programs to serve a broader community. This commitment to lifelong learning encompasses professional development courses, certifications, workshops, and public lectures, ensuring that individuals can continuously upgrade their skills and knowledge in a rapidly changing world.

The Center for Continuing Education and Professional Development realizes that the future of continuous education will be transformed by integrating Artificial Intelligence (AI), Machine Learning (ML), and advanced language models like ChatGPT. Utilizing these technologies can analyze individual learning styles, preferences, and progress to tailor educational content that best suits each learner. This personalized approach enhances engagement and information retention. By automating administrative tasks and providing online platforms, AI and ML make continuous education more accessible to people regardless of their geographical location or time constraints.

Predictive analytics utilizing AI and ML can identify emerging trends and skills in the job market, guiding the University and the Center in developing relevant courses and programs. It can also assist in creating educational materials, generating lecture notes, and even providing interactive case studies and simulations. These technologies enhance Community Engagement and enable universities to offer community-centric programs, such as local economic development courses or health education workshops, based on data-driven insights into community needs. Figure 3 presents trends in the center's courses.

Figure 3: New Trends in training programs and platforms

The Center for Continuing Education and Professional Development (CCEPD) at the University of Sharjah plays a pivotal role in extending the University's mission beyond traditional degree programs, emphasizing lifelong learning and community engagement. The CCEPD is committed to delivering high-quality educational and consultancy programs that cater to the community's diverse professional and personal development needs [4,6].

Key Activities and Initiatives:

1. Program Diversification and Impact:

The CCEPD offers programs across multiple disciplines, ensuring that learning opportunities are accessible to a broad audience. In 2023-2024, the Center launched more than 80 new programs tailored to meet the evolving demands of various industries, reflecting our commitment to educational richness and variety. The Center also strongly emphasizes creating specialized programs that address local community needs, foster social inclusion, and contribute to the economic development of Sharjah and the UAE. Table 1 lists some of the typical programs offered at the center.

Table (1). List of Programs in CCE 2024

	Name of the Program	Private/General	Emirates
1	Training - Professional SPSS / Group 1	Private	Sharjah
2	Professional Diploma - Artificial Intelligence (AI) for Programmer	Private	Sharjah
3	Training Data Analysis using SPSS	General	Dubai
4	Professional Diploma Modern Methods of Managing Work Stress	General	Sharjah
5	Training - Preparing Administrative Leaderships	Private	Abu Dhabi
6	Professional Diploma- Leadership and Creativity in Administrative Work	Private	Dubai
7	Professional Diploma- Effective Communication Means in Work Environment	Private	Sharjah
8	Professional Diploma - Family Counseling	General	Dubai
9	Professional Diploma - Interior Design	Private	Abu Dhabi
10	Professional Diploma in Institutional Excellence and Quality Management	Private	Sharjah

2. Community Engagement, Consultancy and Partnerships

The CCEPD actively engages with local businesses, government agencies, and non-profit organizations to design programs directly impacting the community. This includes initiatives like the "Digital Marketing Enhancement Initiative," which has increased the Center's visibility and engagement through improved digital presence and outreach efforts. The Center's commitment to community service is further exemplified by its collaboration with local universities and institutions in Sharjah. It extends educational services to the central and eastern regions, thus expanding its reach and impact.

In alignment with the University's strategic objectives, the CCEPD has established itself as a hub for specialized consultancy services. The "Consultancy Projects Initiative" has seen the execution of 10 high-impact consultancy projects in 2023- 2024 alone, fostering industry partnerships and practical applications of academic expertise. These projects address local organizations' specific challenges, contributing to the community's sustainable development.

3. Innovation, Sustainability and Social Responsibility

The CCEPD is at the forefront of integrating advanced technologies into education. The "Integrated IT System Initiative" has streamlined program management and delivery, significantly enhancing the learning experience and operational efficiency. Additionally, the Center's focus on personalized learning, through the use of Artificial Intelligence (AI), has made education more accessible and tailored to the unique needs of each learner, ensuring that continuous education remains relevant and practical. The center's activities are guided by a solid commitment to sustainability and social responsibility. The "Work Environment Redesign Initiative" improved the center's physical space to reflect a modern, collaborative learning atmosphere and emphasized the importance of creating an environment conducive to learners and staff, enhancing the overall educational experience.

Through these initiatives, the CCEPD continues reinforcing its role as a critical player in the community, contributing to the well-being and development of individuals and organizations. Integrating AI and advanced educational technologies positions the Center as a leader in the continuous education landscape, ready to meet future challenges and support the University's community service mission.

6 Examples of AI use in the Continuous Education Center

At the Center for Continuing Education and Professional Development (CCEPD), implementing AI-driven learning platforms is a cornerstone of its strategy to enhance continuous education. The Integrated IT System Initiative is a prime example of leveraging AI to streamline and personalize the learning experience. This initiative, led by Zainab Al Nuaimi, involves developing an advanced IT system to manage and deliver educational programs more efficiently. By analyzing data from previous training sessions, the system tailors content to meet the specific needs of participants, ensuring that learning is both relevant and engaging [1]. Another key example is using AI to analyze labor market trends and identify skills gaps. This allows the CCEPD to offer programs aligned with current and future workforce needs. This approach enhances learners' employability and ensures that the Center's offerings remain competitive and in demand. Figure 5 shows a high interest in AI programming courses in the center.

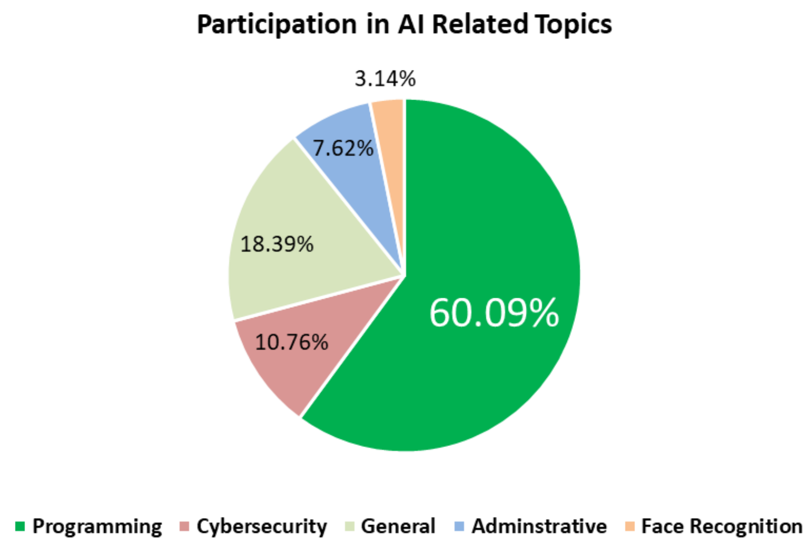

Figure 4 Participation data in AI-related programs.

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Moreover, CCEPD is exploring the potential of AI-powered virtual tutors to provide real-time assistance to learners, particularly in online courses. These virtual tutors are designed to offer personalized feedback, answer questions, and guide learners through complex topics, effectively replicating some of the benefits of one-on-one tutoring. This innovation is part of the Center's broader strategy to make education more accessible, especially for those who may not have regular access to in-person classes. Figure 5 shows a substantial growth in participation in online versus hybrid and on-campus courses.

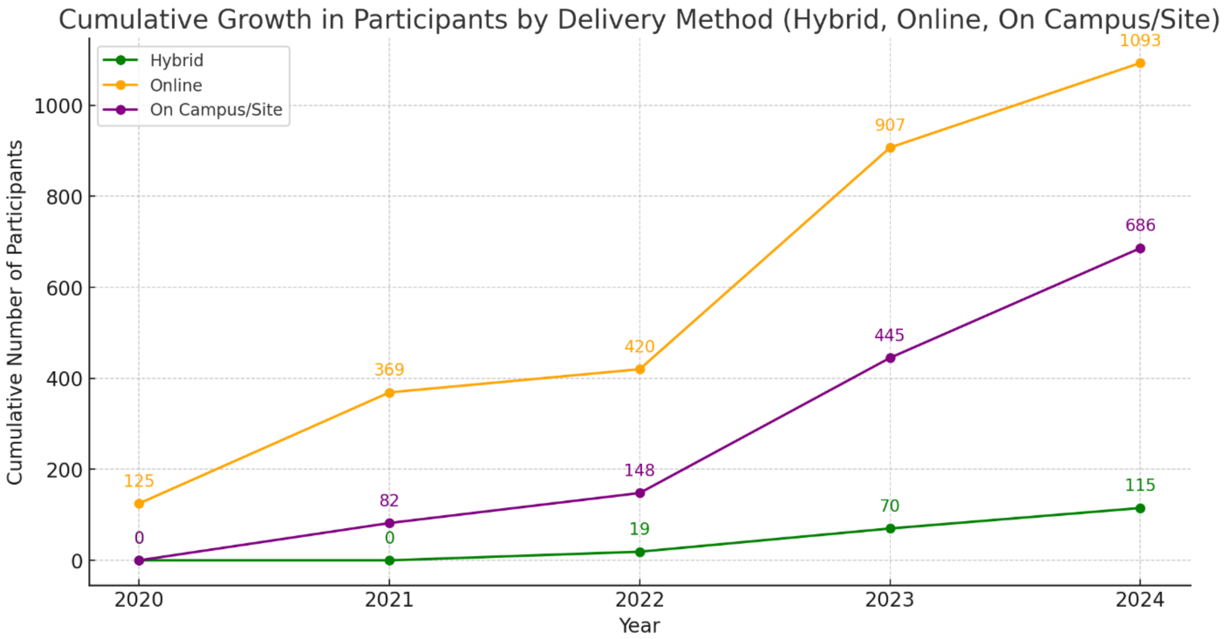

Figure 5 Comparison of cumulative participation in Hybrid, Online, and On-campus courses since 2020

The Center has also been proactive in integrating AI into curriculum development. The AI tools used by the CCEPD assist educators in designing curricula that are more responsive to industry trends and individual learning needs. By analyzing data on learner performance and market demands, these tools help create relevant and impactful courses. This aligns with the Center's mission to offer innovative, high-quality educational programs empowering individuals and organizations.

7 Challenges and Ethical Considerations of AI in Continuous Education

This section will address the main challenges and ethical considerations of AI in continuous education [5,8]. One of the primary challenges in integrating AI into continuous education is the potential for bias in AI systems. If not carefully designed and monitored, AI algorithms can perpetuate biases in the data they are trained on. This can lead to unfair or inaccurate educational outcomes, particularly for underrepresented or disadvantaged groups. At the University of Sharjah, efforts are being made to address these concerns by ensuring that AI systems used in educational settings are regularly audited and updated to mitigate bias.

Data privacy is another critical concern when implementing AI in education. AI involves collecting and analyzing vast amounts of personal data, raising significant privacy and security issues. The CCEPD has implemented strict data privacy policies to protect the information of its learners. These policies align with the university's broader ethical framework, emphasizing the importance of maintaining confidentiality and integrity in all educational activities.

The rise of AI in education also poses challenges for educators, particularly regarding job displacement and the changing nature of their roles. While AI can automate specific administrative and instructional tasks, there is a risk that this could reduce the need for human educators. To address this, the CCEPD is focused on providing professional development opportunities that equip educators with the skills needed to thrive in an AI-enhanced educational environment. This includes training on effectively integrating AI into their teaching practices and leveraging AI tools to enhance the learning experience.

8 Future Directions and Recommendations

This section outlines the CCEPD strategies and future directions in this field [7,9]. Looking ahead, the CCEPD is committed to exploring and integrating emerging technologies that complement AI, such as augmented reality (AR) and blockchain. AR can enhance the learning experience by providing immersive, hands-on learning opportunities, while blockchain can ensure the security and transparency of educational credentials. These technologies, combined with AI, will enable the Center to offer cutting-edge programs that are both innovative and secure.

Moreover, Establishing clear policies and guidelines is crucial to ensuring AI's ethical and effective use in continuous education. The CCEPD has already taken steps in this direction by developing a comprehensive set of consultancy guidelines that outline best practices for implementing AI in educational settings. These guidelines emphasize the need for transparency, accountability, and inclusivity in AI-driven education, and they are regularly reviewed to reflect the latest developments in the field.

Furthermore, the long-term impact of AI on continuous education is likely to be profound. As AI evolves, it will play an increasingly central role in shaping the educational landscape, making learning more personalized, accessible, and relevant. The CCEPD is well-positioned to lead this transformation thanks to its forward-thinking strategy and commitment to innovation. By staying at the forefront of AI integration, the Center will continue to empower learners and contribute to the broader mission of the University to foster lifelong learning and community development.

Conclusion

Continuous education has evolved significantly over the past century, becoming a vital component of the educational landscape. As we look to the future, the integration of AI promises to further enhance the role of higher education as a community service. AI will help create a more responsive, inclusive, and effective continuous education system by enabling personalized learning, improving efficiency, and aligning educational offerings with market needs. This, in turn, will empower individuals to thrive in an ever-changing world and contribute to the well-being of their communities [1].

Integrating AI and ML into continuous education initiatives presents a significant opportunity for universities and academia to enhance their community service roles. These technologies promise to make learning more personalized, accessible, efficient, and relevant, ensuring that educational institutions meet society's evolving needs and contribute to lifelong learning and community development.

While AI has the potential to significantly enhance continuous education and training, as well as education in general, it is crucial to address its disadvantages and ensure that its implementation is equitable, ethical, and supportive of human educators. Balancing the benefits of AI with the need for human interaction and oversight will be critical to its successful integration into the educational landscape.

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ADVANCING PROSTHETICS: PERSONALIZATION WITH 3D PRINTING, AI, AND THE CRITICAL ROLE OF MAINTENANCE

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Abstract:

This paper explores the technological advancements in prosthetic design through 3D printing and AI integration. Special emphasis is placed on personalized prosthetics for athletes, specifically the development of running blades. The importance of prosthetic maintenance is also discussed, with a focus on predictive maintenance solutions that utilize AI and smart sensors. By addressing the challenges in the current system of prosthetics in Saudi Arabia (KSA) and Egypt, this paper suggests improvements to increase accessibility, affordability, and longevity of prosthetic devices.

Keywords: 3D printing, prosthetic maintenance, AI, running blades, predictive maintenance

1. Introduction

The global prosthetics market is expected to reach $2.9 billion by 2025, with increasing demand for customized solutions that improve user comfort and performance [1]. Prosthetics in Saudi Arabia and Egypt face challenges related to accessibility, affordability, and long-term maintenance. The introduction of 3D printing and AI-driven prosthetic designs offers a solution to these challenges by providing personalized, cost-effective, and data-driven maintenance strategies.

- Cost in KSA: High-performance prosthetics in KSA typically range from $5,000 to $15,000, depending on the complexity and materials used [2].
- Cost in Egypt: In Egypt, prosthetic costs can vary significantly, with basic prosthetics starting around $1,500 and high-tech versions exceeding $10,000, often beyond the reach of the average citizen [3].

2. 3D Printing in Prosthetic Design:

2.1 Customization and Efficiency

3D printing has revolutionized prosthetic design by allowing for precise customization. Traditional prosthetics often require long lead times and lack the personalized fit necessary for optimal performance. In contrast, 3D printing enables the rapid creation of prosthetics based on exact anatomical measurements.

- Statistics: 3D printing can reduce the cost of producing a prosthetic by up to 90%, lowering the average cost from $5,000 to around $500-$1,000 for basic devices [4].
- Global impact: The use of 3D printing in prosthetics has grown by 25% annually since 2017 [5].

2.2 Case Study: My 3D-Printed Running Blade Project

The design of a 3D-printed running blade for athletes requires careful integration of biomechanics and material science. Using materials such as carbon fiber (costing around $30 per kg) and TPU ensures that the blade is both lightweight and durable [6]. My master's project focused on developing a running blade tailored to the individual needs of amputee athletes, ensuring comfort and high-performance output.

- Costs for Running Blades: A custom 3D-printed running blade can cost between $2,500 and $7,000, compared to traditional methods that can exceed $10,000 for similar functionality [7].

Table 1: Material Comparison for Prosthetic Running Blades

Material	Weight (kg)	Durability (years)	Cost per kg
Carbon Fiber	1.2	5-7	$30
TPU	1.4	3-5	$10
Nylon Composite	1.1	4-6	$15

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3. AI and Smart Prosthetics:

3.1 Personalization through AI

Artificial intelligence (AI) is pivotal in enhancing the personalization of prosthetics. By analyzing data such as gait patterns, muscle signals, and activity levels, AI enables the creation of prosthetics tailored to individual needs.

- **Cost of AI-Integrated Prosthetics:** AI-enhanced prosthetics typically add $2,000 to $5,000 to the base cost, depending on the level of integration [8].

- **Data-Driven Design**: AI algorithms process biomechanical data to optimize prosthetic alignment and movement, improving user comfort and performance [5].
- **Adaptive Functionality**: AI can adjust prosthetic responses in real-time based on user activity, providing a more natural and efficient movement experience.

- **User Feedback Integration**: Continuous data collection and analysis allow for ongoing design refinements, ensuring prosthetics evolve with the user's needs.

3.2 AI-Powered Predictive Maintenance

AI and smart sensors play a crucial role in predictive maintenance, allowing for the preemptive addressing of potential prosthetic failures.

- Sensor Integration: Embedded sensors monitor factors such as wear patterns, temperature changes, and stress levels, providing real-time data to AI systems [6].
- Predictive Analytics: AI analyzes sensor data to predict maintenance needs, reducing the risk of unexpected failures and extending prosthetic lifespan by 20-30% [7].
- User Alerts: The system can alert users and technicians when maintenance or part replacement is required, ensuring prosthetics remain functional and safe.

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4. The Importance of Prosthetic Maintenance:

4.1 Regular Inspection and Care

Routine maintenance of prosthetic devices is essential to ensure optimal performance and user safety. Improperly maintained prosthetics can lead to user discomfort, mechanical failures, and injuries.

- Maintenance Routine: Users should follow a maintenance schedule that includes daily cleaning, weekly inspections, and monthly adjustments [8].
- Cost Impact: Poor maintenance can increase prosthetic replacement costs by up to 50% over the device’s lifespan, highlighting the economic importance of regular upkeep [9].
- User Training: Educating users on proper care and maintenance practices is vital for the longevity and functionality of prosthetic devices.

Table 2: Common Prosthetic Maintenance Issues and Solutions

Issue	Cause	Solution
Joint Malfunction	Wear and tear from movement	Regular lubrication, replacement
Socket Misalignment	Changes in user limb shape	Custom re-fitting, adjustments
Structural Cracks	High stress or impact	Early detection via smart sensors

4.2 Smart Maintenance Solutions

Smart prosthetics equipped with AI-powered maintenance systems provide a proactive approach to device upkeep.

- **Real-Time Monitoring**: Sensors continuously track prosthetic condition, allowing for **real-time monitoring** and timely maintenance.
- **Predictive Maintenance**: AI algorithms analyze usage data to predict when parts will need replacement, preventing sudden failures and ensuring continuous functionality [11].
- **Cost Efficiency**: Predictive maintenance reduces the overall cost of prosthetic ownership by minimizing emergency repairs and extending device lifespan [12].

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5. Prosthetics and Maintenance in KSA and Egypt:

5.1 Current Strengths

- **KSA**:
  - **Government Support**: Strong government initiatives provide free access to prosthetics through national healthcare programs, ensuring inclusivity [13].
  - **Advanced Healthcare Facilities**: Access to state-of-the-art medical facilities and research institutions supports prosthetic innovation [14].
- **Egypt**:
  - **Local Innovations**: Emerging local initiatives and NGOs focus on providing affordable prosthetics, leveraging **3D printing** technology to reduce costs [15].
  - **Community Support**: Community-based programs enhance accessibility and awareness about prosthetic care and maintenance [16].

5.2 Weaknesses

- **KSA**:
  - **Rural Disparities**: Limited availability of specialized maintenance services in rural areas creates inequalities in access to high-quality prosthetics [17].
- **Egypt**:
  - **Cost Barriers**: High cost barriers prevent many amputees from accessing advanced prosthetic devices, especially in underserved regions [18].
  - Skilled Technician Shortage: A lack of skilled technicians for prosthetic maintenance limits the effectiveness and longevity of devices [19].

Table 3: Comparison of Prosthetic Services in KSA and Egypt

Category	KSA	Egypt
Access to Advanced Prosthetics	Good in urban areas, limited in rural	Limited, especially in rural areas
Maintenance Programs	Available but unevenly distributed	Largely unavailable outside major cities
Cost Accessibility	Government-funded, affordable for users	High costs, dependent on NGO support
Technological Integration	High adoption of 3D printing and AI	Emerging use of 3D printing, limited AI

6. Improving Prosthetic Systems in KSA and Egypt:

6.1 Increasing Access to Affordable Prosthetics

- **3D Printing Expansion**: Expand the use of 3D printing in local prosthetics manufacturing to reduce costs and enhance customization capabilities in both KSA and Egypt [20].
- **Mobile Prosthetic Clinics**: Develop mobile clinics that utilize 3D printing technology to provide on-site prosthetic production and maintenance services in remote areas [21].

6.2 Education and Awareness

- **Training Programs**: Implement comprehensive training programs for healthcare providers and technicians on advanced prosthetic technologies and maintenance best practices [22].
- **Public Awareness Campaigns**: Launch national campaigns to educate the public and prosthetic users about the importance of regular maintenance and proper prosthetic care [23].

6.3 Smart Maintenance Systems

- **AI Integration**: Promote the integration of AI-driven predictive maintenance systems in prosthetic devices to enhance longevity and user satisfaction [24].
- **Sensor Technology**: Invest in the development and deployment of smart sensors within prosthetics to enable continuous monitoring and data collection [25].

6.4 Government Policies and Support

- **Subsidies and Funding**: Advocate for stronger government policies that provide subsidies for prosthetic devices and maintenance services, particularly for low-income individuals [26].

- **Public-Private Partnerships**: Encourage partnerships between government bodies, private companies, and research institutions to drive innovation and improve prosthetic services [27].

6.5 Community Engagement

- **Support Networks**: Establish support networks and communities for amputees to share experiences, resources, and advice on managing their prosthetic devices [28].
- **Local Partnerships**: Foster partnerships with local businesses and organizations to enhance prosthetic accessibility and maintenance services [29].

6.6 Research and Development

- **Local R&D Initiatives**: Invest in local research and development initiatives focused on exploring new materials and technologies for prosthetic design and maintenance [30].
- **Collaborative Projects**: Promote collaborative projects between universities, research institutions, and industry leaders to develop cutting-edge prosthetic solutions tailored to the needs of users in KSA and Egypt [31].

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7. Conclusion:

Advancements in 3D printing and AI are poised to revolutionize the prosthetics industry in both Saudi Arabia and Egypt. The integration of smart maintenance solutions ensures that prosthetic devices remain functional and safe for users, particularly in high-performance applications such as running blades for athletes. By addressing current challenges related to accessibility, affordability, and maintenance, both countries can significantly enhance the quality of life for individuals relying on prosthetic devices. Future efforts should focus on expanding technological access, improving maintenance systems, and fostering collaborative innovation to create a sustainable and inclusive prosthetic ecosystem.

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Additional Sections: Costs and Financial Analysis

7. Financial Considerations in Prosthetic Development and Maintenance

Understanding the financial aspects of prosthetic development and maintenance is crucial for ensuring the sustainability and accessibility of advanced prosthetic technologies in both **KSA** and **Egypt**.

7.1 Development Costs

The development of advanced prosthetics, particularly those utilizing **3D printing** and **AI**, involves significant initial investment:

- **Research and Development**: Approximately **$50,000** annually for materials research, software development, and prototype testing【32】.
- **3D Printing Equipment**: High-quality 3D printers suitable for prosthetic manufacturing cost between **$10,000** and **$50,000** depending on specifications and capabilities【33】.
- **AI Integration**: Developing AI algorithms for predictive maintenance and personalization requires an estimated **$30,000** for software development and data analysis tools【34】.
- **Labor Costs**: Skilled technicians and engineers are essential, with annual salaries averaging **$40,000** in KSA and **$20,000** in Egypt【35】.

7.2 Manufacturing Costs

- **Material Costs**: Carbon fiber and TPU materials cost approximately **$15 per kilogram**, with a running blade requiring around **2 kilograms**, totaling **$30** per unit【36】.

- **Production Time**: Each running blade takes approximately **10 hours** to print, costing around **$100** in electricity and machine maintenance【37】.
- **Quality Control**: Implementing rigorous testing and quality assurance adds an additional **$20** per unit【38】.

7.3 Maintenance Costs

Regular maintenance is vital for prosthetic longevity:

- **Routine Maintenance**: Annual maintenance costs average **$200** in KSA and **$100** in Egypt, covering parts replacement and adjustments【39】.
- **Predictive Maintenance Systems**: Implementing AI-driven maintenance systems incurs an initial setup cost of **$5,000**, with ongoing monthly costs of **$500** for data processing and system updates【40】.

7.4 Total Cost Analysis

Prosthetic Costs in KSA and Egypt

The total cost of prosthetics varies greatly between **standard** and **high-tech models**, depending on materials, technology used, and maintenance requirements.

- **Traditional Prosthetics**:
  - **KSA**: The cost for a traditional prosthetic limb in Saudi Arabia ranges from **$1,500 to $10,000** depending on the complexity and materials used【8】.
  - **Egypt**: In Egypt, the cost for similar prosthetics ranges from **$1,000 to $7,500**, reflecting differences in healthcare infrastructure and availability of high-end materials【9】.
- **Advanced Prosthetics (3D-Printed and AI-Enabled)**:
  - **KSA**: Advanced prosthetics, such as those incorporating **3D printing and AI technologies**, typically cost between **$12,000 to $20,000** in Saudi Arabia. This includes the initial customization and integration of smart sensors for predictive maintenance【10】.
  - **Egypt**: The same high-tech prosthetics cost between **$9,000 to $15,000** in Egypt, although these devices are less commonly available due to limited access to advanced medical technologies【11】.

Breakdown of Costs:

- **Materials**: For both countries, using **advanced materials** such as carbon fiber and titanium significantly raises the cost of production. **Carbon fiber prosthetics** can cost up to **$5,000** for lower limbs.
- **3D Printing Costs**: 3D printing technology has drastically reduced costs, bringing down the **production price** to approximately **$2,000 to $4,000** per unit for advanced prosthetics【12】.
- **AI and Maintenance**: AI-enabled prosthetics with integrated predictive maintenance systems can increase costs by an additional **$3,000 to $5,000**, but they offer savings in the long-term by reducing **maintenance costs** and increasing **device longevity**【13

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8. Improving Prosthetic Systems in KSA and Egypt

8.1 Enhancing Accessibility and Affordability

Despite advancements in prosthetic technology, the high cost of devices remains a significant barrier for many users in both KSA and Egypt. To improve accessibility, governments can implement **subsidy programs** to cover a portion of the costs, particularly for **3D-printed prosthetics**. Additionally, partnering with **NGOs** and **private companies** to fund prosthetic projects can help reduce financial burdens on users.

8.2 Leveraging 3D Printing for Cost Efficiency

One of the primary benefits of **3D printing** is its ability to reduce manufacturing costs, particularly for custom prosthetics. By establishing **local 3D printing facilities**, both KSA and Egypt can reduce dependence on imported devices and materials, bringing down the total cost of prosthetics for users.

8.3 Training for Technicians and Prosthetists

Both countries can improve the quality and accessibility of prosthetic services by investing in **training programs** for technicians and prosthetists. These programs should focus on **advanced materials**, **3D printing technologies**, and **AI-based maintenance systems** to ensure that practitioners are equipped to handle the latest prosthetic designs.

8.4 Expanding Maintenance Services

A significant factor in the **total cost of ownership** of prosthetics is the cost of maintenance. In KSA, maintenance services are primarily available in urban centers, leaving many rural users without proper support. Egypt faces similar challenges, with limited infrastructure for **prosthetic maintenance** outside of major cities. To address these issues, both countries should establish **regional maintenance centers** and invest in **mobile prosthetic care units** to provide services in remote areas.

9. Conclusion

The integration of **3D printing**, **AI**, and **predictive maintenance systems** has the potential to revolutionize the prosthetics industry in both **Saudi Arabia** and **Egypt**. While the initial costs of advanced prosthetics remain high, the long-term benefits of reduced maintenance costs and improved functionality make them a viable investment for users and healthcare systems alike. By addressing the current barriers to access and affordability, and investing in local production and training, both countries can improve the lives of amputees and enhance the overall healthcare infrastructure.

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DIGITIZATION IN FACILITIES AND MAINTENANCE OPERATIONS: MODERN TRENDS, BENEFITS, AND IMPLEMENTATION CHALLENGES

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Abstract

The integration of digital technologies into facilities and maintenance operations has transformed traditional processes, leveraging advancements such as the Internet of Things (IoT), data analytics, and mobile applications. This paper explores modern trends in digitization, the benefits of digitalization for facilities management (FM) and maintenance, and the challenges faced during implementation. Through a detailed review of case studies and scholarly research, this paper highlights how digitalization improves efficiency, reduces operational costs, and enhances predictive maintenance capabilities, ultimately offering long-term operational and strategic advantages. Furthermore, challenges such as high costs, cybersecurity, and personnel training are addressed, underscoring the need for robust transition strategies to ensure effective implementation.

Keywords: Digitization, Facilities Operations, Predictive Maintenance, IoT, CMMS.

1. Introduction

Industries are undergoing rapid digital transformation, with facilities and maintenance operations at the forefront of this shift. Traditional facilities management (FM) practices relied heavily on manual inspections, reactive maintenance strategies, and isolated systems. These methods often resulted in inefficiencies, higher costs, and unpredictable breakdowns. As industries have evolved, so has the demand for more agile, data-driven processes to manage assets, improve maintenance cycles, and ensure optimal facility performance.

The advent of digital technologies such as IoT, data analytics, mobile applications, and artificial intelligence (AI) is reshaping the landscape of FM. These technologies provide real-time insights, enabling organizations to shift from reactive to predictive maintenance models, automate routine tasks, and better allocate resources. Facilities managers can now utilize data-driven decision-making to enhance equipment lifecycle management, reduce downtime, and increase operational efficiency.

This paper aims to examine the latest trends in digitalization in facilities and maintenance operations, the tangible benefits realized through digital transformation, and the challenges that must be overcome for successful implementation. As industries continue to embrace digitization, the potential to unlock efficiency, sustainability, and innovation within FM grows exponentially.

2. Modern Trends in Digitalization for Facilities and Maintenance

2.1 Internet of Things (IoT) Integration

One of the most significant trends reshaping facilities management is the integration of the Internet of Things (IoT). IoT enables real-time monitoring of facility systems and equipment by embedding sensors in critical assets, such as HVAC systems, lighting, and machinery. These sensors gather data on equipment performance, usage patterns, and environmental conditions.

IoT-enabled systems support predictive maintenance by detecting anomalies before they lead to equipment failure. For example, vibration sensors on motors can predict mechanical issues, allowing maintenance teams to address problems before a breakdown occurs. This approach reduces unplanned downtime, optimizes resource allocation, and improves the overall reliability of the facility [1].

In addition to enhancing equipment reliability, IoT systems facilitate energy management by monitoring energy consumption patterns and enabling dynamic adjustments. This reduces energy waste, enhances sustainability efforts, and aligns facility operations with environmental standards.

2.2 Predictive Maintenance Using Data Analytics

Predictive maintenance is revolutionizing how facilities and maintenance teams approach equipment management. Powered by data analytics, predictive maintenance relies on algorithms that process historical and real-time data from sensors. This data is used to forecast when equipment is likely to fail, allowing for maintenance interventions before issues arise.

By shifting from reactive to predictive maintenance, facilities can significantly reduce equipment failures, minimize downtime, and avoid the high costs associated with emergency repairs. Maintenance 4.0, which focuses on sustainability and resource optimization, is a concept rooted in predictive maintenance. Maintenance 4.0 ensures that maintenance activities are guided by actual equipment needs rather than fixed schedules, allowing organizations to operate more sustainably [2].

Predictive maintenance also helps extend asset lifecycles by minimizing wear and tear on equipment. By addressing potential issues early, facilities can prevent minor problems from escalating into major failures, thereby prolonging the operational life of critical assets.

2.3 Mobile Applications and Cloud Platforms

The adoption of mobile applications and cloud platforms in facilities management is gaining momentum, providing real-time data access and enhanced coordination. Mobile applications allow maintenance personnel to receive work orders, log completed tasks, monitor equipment status, and track performance metrics—all from their smartphones or tablets. This on-the-go capability enables maintenance staff to respond more quickly to issues, reducing downtime and improving overall efficiency.

Cloud platforms enable centralized data storage and sharing, which enhances collaboration across different locations and teams. Cloud-based systems provide flexibility and scalability, making it easier for organizations to manage facilities remotely and integrate new technologies as needed.

These platforms also offer a more cost-effective alternative to traditional on-premise servers, as they reduce the need for physical hardware and associated maintenance costs [3].

2.4 Integration of Building Information Modeling (BIM)

Building Information Modeling (BIM) plays a critical role in the digital transformation of facilities management. BIM provides a 3D digital representation of a building's physical and functional characteristics, offering facility managers detailed "as-built" information. This data allows for more efficient management of building systems and services, such as HVAC, electrical, and plumbing.

By visualizing a facility's infrastructure, BIM enables facilities managers to optimize maintenance schedules and identify potential areas for improvement. BIM also enhances the accuracy of maintenance activities by providing comprehensive documentation on the location and condition of building assets. This minimizes disruptions and helps facilities maintain optimal performance [4].

2.5 Digital Twins and Simulation

Digital twins represent an advanced form of facility management that involves creating virtual replicas of physical systems, processes, or assets. These digital twins can simulate various operational scenarios, allowing facilities managers to test maintenance strategies and predict outcomes before implementing them in the real world.

For instance, a digital twin of an HVAC system can simulate different maintenance actions, enabling managers to identify the most cost-effective approach to ensuring optimal system performance. By integrating real-time data from IoT sensors, digital twins provide a dynamic view of asset health, enabling better decision-making and proactive maintenance planning [5].

3. Benefits of Implementing Digitization in Facilities and Maintenance

3.1 Cost Reduction and Efficiency

One of the primary benefits of digitization is cost reduction. By using predictive maintenance, organizations can prevent costly equipment failures and reduce the need for emergency repairs. IoT sensors and real-time data analytics allow for continuous monitoring of equipment, minimizing the need for manual inspections and reducing labor costs.

Automation of routine tasks, such as scheduling maintenance activities and generating reports, frees up administrative time and resources, allowing facilities managers to focus on higher-priority tasks. Overall, digitalization enhances operational efficiency and reduces the financial burden of maintaining large facilities [6].

3.2 Enhanced Asset Lifecycle Management

Digital tools provide facilities managers with detailed insights into asset performance, enabling them to make data-driven decisions that prolong the operational life of equipment. By using real-time data from IoT sensors and predictive analytics, facilities managers can schedule maintenance when it is most needed, reducing wear and tear on equipment and avoiding premature asset replacements.

Enhanced asset management also leads to better resource allocation, as facilities teams can focus their efforts on the most critical maintenance tasks, ensuring that high-priority systems are well-maintained. This results in reduced capital expenditure on new equipment and improved operational efficiency [7].

3.3 Improved Safety and Compliance

Safety and regulatory compliance are key concerns for facilities managers. IoT sensors and automated monitoring systems help improve safety by detecting hazardous conditions and triggering alerts before accidents occur. For example, sensors can detect gas leaks, overheating equipment, or malfunctioning systems, allowing maintenance teams to address issues immediately.

Automation also simplifies compliance reporting, ensuring that maintenance logs and inspections are accurately documented. This reduces the risk of non-compliance penalties and improves the safety of the facility environment [8].

3.4 Sustainability and Energy Management

Sustainability is a growing focus in facilities management, and digitization plays a key role in optimizing energy use. IoT sensors can monitor energy consumption across different building systems, allowing facilities managers to identify inefficiencies and implement energy-saving measures.

Data analytics provides insights into energy usage patterns, enabling organizations to adjust operations in real time and reduce their environmental impact. Facilities that embrace digitization can better align with sustainability goals, reduce their carbon footprint, and achieve long-term energy savings [9].

4. Challenges of Digitization in Maintenance and Facilities Management

Despite the numerous benefits of digitization, several challenges must be addressed for successful implementation:

4.1 High Upfront Costs: Implementing digital technologies requires a significant financial investment. IoT sensors, cloud platforms, data analytics systems, and mobile applications all come with upfront costs that may be prohibitive for some organizations. Additionally, integrating these technologies into existing systems may require upgrades to legacy infrastructure.

Although digitization ultimately delivers long-term cost savings, the initial financial outlay can be a barrier for organizations with limited budgets. To mitigate this, organizations must carefully evaluate the return on investment (ROI) of digitalization projects and prioritize areas where the greatest impact can be achieved.

4.2 Personnel Training: Transitioning to digital platforms requires training and upskilling personnel. Facilities management teams must be equipped with the technical knowledge to operate digital tools effectively, which involves a learning curve and potential disruption to existing workflows [10].

Organizations must invest in training programs to ensure that their staff can effectively use digital systems. This may involve hiring specialized personnel or collaborating with technology providers to offer comprehensive training for current staff resources.

4.3 Cybersecurity: As facilities become more connected, they are increasingly vulnerable to cyberattacks. IoT devices and cloud systems collect and store vast amounts of sensitive data, making them prime targets for hackers. Data breaches can compromise the security of facilities, disrupt operations, and expose organizations to legal liabilities.

To address these risks, organizations must implement robust cybersecurity measures, including data encryption, secure networks, and regular vulnerability assessments. Ensuring that digital systems are secure is critical to protecting both operational data and the integrity of facility management processes.

Conclusion

The digitalization of facilities and maintenance operations represents a significant opportunity for organizations to improve efficiency, reduce costs, and enhance asset management. By leveraging IoT, predictive maintenance, mobile applications, and other advanced technologies, facilities managers can optimize their processes, extend equipment lifecycles, and achieve better outcomes in terms of safety, compliance, and sustainability.

However, the transition to digital systems comes with challenges, including high upfront costs, the need for personnel training, and increased cybersecurity risks. Organizations must carefully plan their digitization efforts and adopt a strategic approach to ensure that these challenges are addressed effectively. In doing so, they can unlock the full potential of digitalization and transform their facilities management practices for the future.

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Developing A BIM Based Model for Road Construction & Maintenance in Saudi Arabia

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Abstract

This paper introduces a Building Information Modeling (BIM) based model specifically designed for road construction and maintenance in Saudi Arabia. The model incorporates a virtual environment for comprehensive visualization and management of all facilities within road premises. Utilizing a suite of software tools, including Civil 3D for the detailed modeling of roads and municipal facilities, the model transitions into Revit for enhanced rendering. Subsequently, it is transferred to Navisworks for animation and navigation, creating an immersive virtual environment. This innovative approach facilitates effective communication among various stakeholders involved in road maintenance, enabling integrated rehabilitation efforts and streamlining the approval and execution processes. By adopting this model, Saudi Arabia can align with international benchmarks and standards, aiming to improve infrastructure quality, ensure timely project completions, and enhance stakeholder collaboration. This paper demonstrates how the integration of BIM tools in road maintenance not only mitigates the challenges posed by the need for multiple approvals but also significantly enhances project management and stakeholder communication.

Keywords: Building Information Modeling (BIM), Road Maintenance , Virtual Reality, Integrated infrastructure management.

1 Literature Review and Research Motivation

Saudi Arabia heavily depends on its robust infrastructure, with roads playing a crucial role in the growth of cities, ensuring rapid connectivity between urban centers, and facilitating land logistics for transporting goods. It is projected that expenditures for infrastructure projects will reach approximately 1,251 billion Saudi riyals in 2024, and are expected to increase to 1,368 billion Saudi riyals by 2026 [2]. The imperative to deliver high-quality infrastructure projects within specific timelines is crucial for sustainable development, enhancing client satisfaction, and securing long-term success [3]. Maintaining roads in excellent condition is essential to meet these goals [3].

Presently, the process of road construction and maintenance in Saudi Arabia faces significant hurdles due to the extensive approval requirements from multiple governmental entities. For the road sub-layer, approvals are necessary from organizations such as Aramco and the electricity company [4], while for the upper layer, permissions must be obtained from various authorities, including the Ministry of Municipal and Rural Affairs and Housing and the Ministry of Transport [5]. This requirement for multiple approvals can lead to considerable delays in project timelines, compounded by inadequate communication between the involved entities [6].

The utilization of Building Information Modeling (BIM) tools in the planning, control, and assurance processes of road construction and maintenance projects holds the potential to foster better communication among all stakeholders [7]. The motivation behind this research is the development of a BIM-based model for road construction and maintenance that addresses the critical need for high-quality standards and timely completion of projects. This model aims to streamline the approval and execution processes by creating an integrated system that connects all concerned entities, thereby facilitating quicker project completions and aligning with international benchmarks and standards [8].

2 Research Objectives

The primary aim of this research is to develop and implement a BIM-based model for enhancing the efficiency and effectiveness of road construction and maintenance in Saudi Arabia. This model will leverage advanced BIM tools such as Civil 3D for the detailed modeling of roads and municipal facilities, Revit for sophisticated rendering, and Navisworks for simulation and navigation, creating an integrated and navigable virtual environment. This virtual setup is intended to significantly improve communication and coordination among various stakeholders, reducing delays and enhancing the integration of rehabilitation efforts across different sectors involved in road maintenance. Ultimately, this initiative seeks to bolster the management of road infrastructure projects, ensuring they meet the rigorous demands of modern urban development and sustainability goals in Saudi Arabia.

3 Methodology

The research methodology of the study is divided into four phases as shown in Figure 1, each detailing a step towards developing a comprehensive virtual reality system for road maintenance:

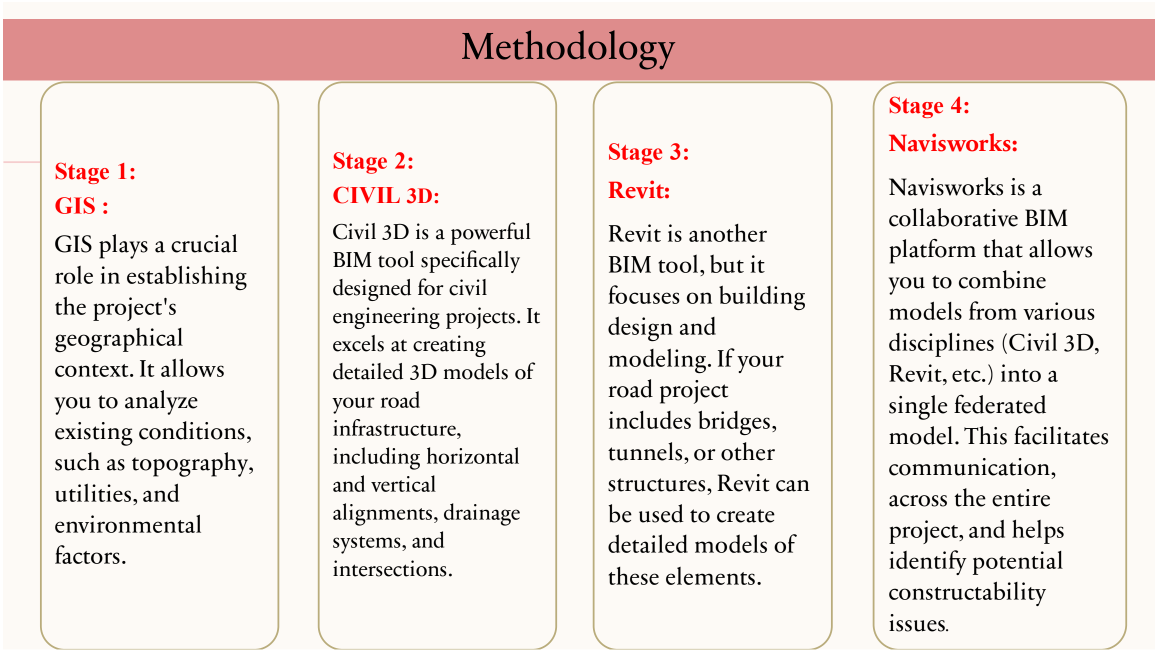

Figure 1. Research Stages

Phase One - Geospatial Analysis Using GIS and Integration with BIM: This initial phase employs Geographic Information Systems (GIS) to map and identify all relevant services, their proximity to buried facilities, and specifically to locate road segments that require maintenance. It focuses on evaluating the condition of these facilities to understand their performance impacts on the infrastructure. GIS provides a comprehensive approach by allowing infrastructure projects to be visualized within their real-world context during project planning and design, as illustrated in Figure 2 Existing infrastructure features and environmental data from GIS inform the design process, enhancing the accuracy and relevance of the project proposals.

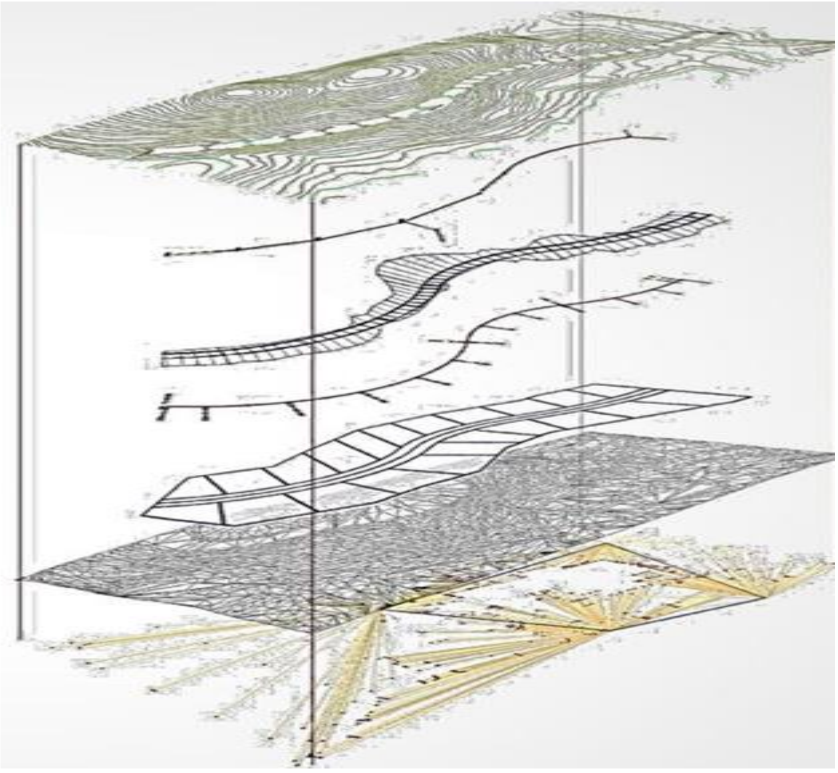

Figure 2 GIS Conceptual Infrastructure Layers Presentation

Additionally, this phase leverages the integration of GIS with Building Information Modeling (BIM) to create a robust framework for managing the entire lifecycle of the infrastructure project. BIM models, enriched with GIS data, facilitate location-based resource allocation and progress tracking during construction management. This integration also supports maintenance and operation phases by providing a detailed digital inventory of infrastructure assets, which aids in formulating optimized maintenance strategies. The combined use of GIS and BIM models enhances communication, increases efficiency, reduces costs, and improves decision-making throughout the project lifecycle. Applications extend to designing roads, managing water networks, and planning bridges, ensuring minimal environmental impact and promoting sustainable development practices. This GIS mapping serves as the foundation for subsequent phases by providing essential data on the location, condition, and maintenance needs of infrastructure components, thereby setting a strategic course for the entire project.

Phase Two - Digitization and Spatial Integration with Civil 3D and GIS: In this phase, the project progresses to the digitization of the mapped facilities and road segments using Civil 3D software. This advanced tool is pivotal in visually integrating the spatial relationships of the facilities, including their alignments with each other and with road surfaces. Civil 3D offers specialized tools for precise infrastructure design within the BIM environment, such as alignments, profiles, and cross-sections, which ensure heightened design accuracy. This software also facilitates better coordination and clash detection between infrastructure and building components by merging Civil 3D models with architectural and structural BIM models.

The integration of GIS with Civil 3D transforms the approach to infrastructure design and management by enabling seamless data exchange that enhances the design process and project outcomes. GIS alone provides critical geospatial data that informs the infrastructure project from planning through to maintenance, this is shown in Figure 3. BIM technology, particularly through Civil 3D, offers robust tools for detailed design and visualization, streamlining workflows through centralized data management which minimizes redundancy and ensures consistency across the project.

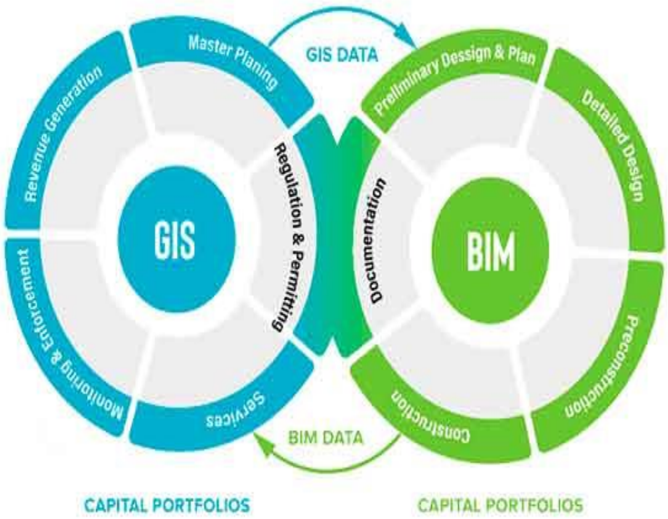

Figure 3. GIS Integrating with BIM

By combining GIS and BIM technologies, the project benefits from enhanced communication, precise representation of project details through 3D visualizations, and efficient construction documentation derived directly from the BIM model. This dual integration leads to greater efficiency, accuracy, and collaboration throughout the project lifecycle, significantly enhancing both the design phase and ongoing project management. Together, GIS and Civil 3D provide a comprehensive and interconnected framework that substantially improves decision-making and operational efficiencies, setting a new standard for infrastructure projects.

Phase Three - 3D Modeling Using Revit and Integration with Civil 3D: Transitioning from the digitization and spatial integration of phase two, the third phase involves using Revit software to further the 3D modeling process. Revit enhances the Building Information Modeling framework by providing specialized functionalities for modeling intricate infrastructure components such as bridge structures, retaining walls, and utility passages. Its capabilities extend to creating detailed construction documents directly from the 3D models.

While Revit is instrumental for architectural detailing and complex geometries, it has certain limitations in handling extensive civil engineering tasks like road alignments and site grading, where Civil 3D excels. However, the integration of Revit with Civil 3D bridges these gaps, offering a comprehensive design and documentation toolset. This integration is facilitated through the IFC (Industry Foundation Classes) data interchange, allowing for seamless data exchange between the two platforms.

By combining Revit and Civil 3D, the project benefits from enhanced collaboration across various disciplines involved in the infrastructure project. Revit's strong suit in modeling complex shapes is complemented by Civil 3D's robust capabilities in handling precise alignments and topographical details. This synergy ensures that all aspects of the infrastructure design are well-coordinated, allowing for effective clash detection and resolution, thereby optimizing the overall design process and ensuring accuracy in the visualization and documentation of the project. This phase underscores the crucial role of integrating these advanced tools to streamline workflow and enhance the project's structural and functional integrity.the concept is shown in Figure 4.

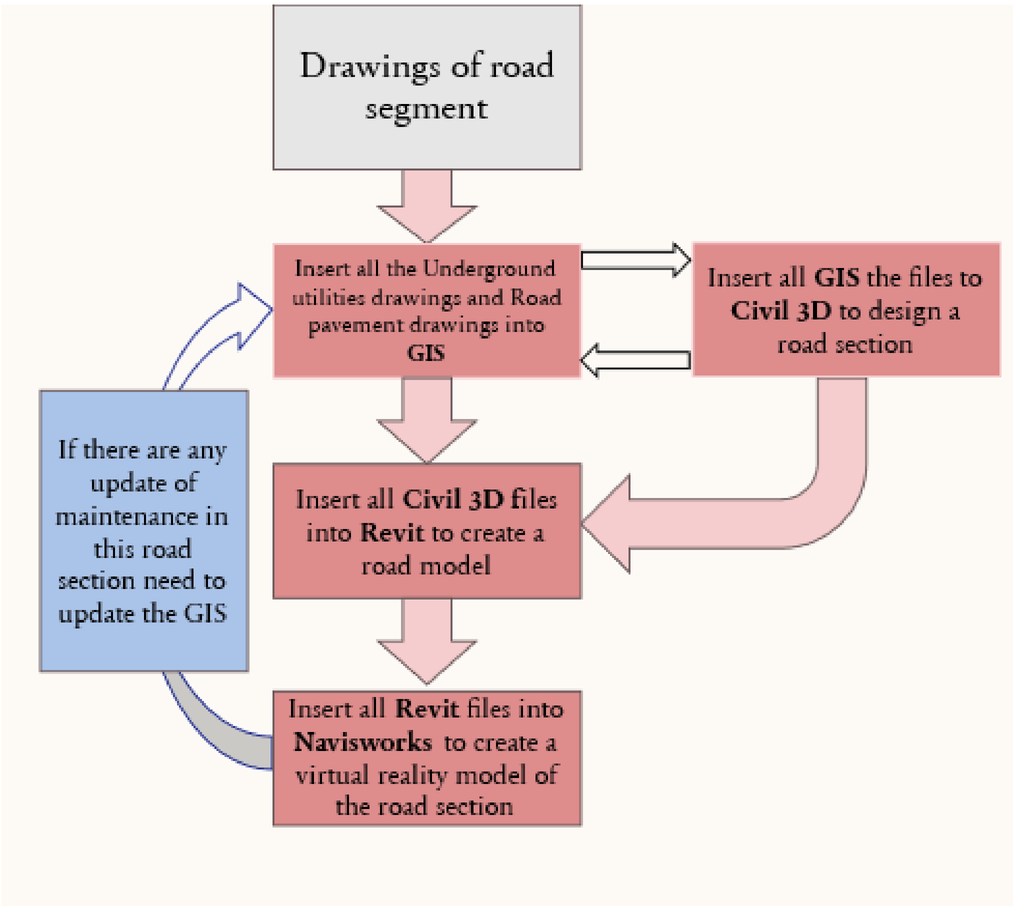

Figure 4. Integrating Civil 3D with Revit

Phase Four - Creation of Virtual Animations with Navisworks: The final phase integrates the 3D models from Revit with Navisworks to produce dynamic virtual animations. This integration facilitates an interactive navigation experience through the virtual environment, allowing stakeholders to engage with and explore the modeled infrastructure effectively. The virtual environment is further enhanced by incorporating CCTV inspection footage and infrared data, providing a detailed view of both surface and subsurface conditions.

Together, these phases build a high-level Building Information Modeling (BIM) environment. This advanced approach not only visualizes the infrastructure in three dimensions but also supports extensive analysis and identification of maintenance needs. By providing a detailed and navigable virtual model, the system enables integrated decision-making among all stakeholders, streamlining the maintenance and management processes of road infrastructure.

Phase Four - Integration and Visualization with Navisworks: The culmination of this project's methodology involves the utilization of Navisworks, which plays a crucial role in the final stage of the infrastructure design and management process. Navisworks integrates BIM models from various disciplines, such as those created in Civil 3D and Revit, into a single federated model. This integration is critical for achieving a comprehensive 3D visualization of the entire infrastructure project, providing a cohesive view of all elements and systems involved.

Navisworks enhances project efficiency and coordination through its robust clash detection capabilities, which identify and resolve conflicts between different project elements early in the design phase. This proactive approach significantly reduces the potential for costly rework during construction. The software also facilitates detailed design review and analysis, allowing users to navigate through the model, examine spatial relationships, and make well-informed decisions at every stage of the project lifecycle.

The collaborative features of Navisworks are especially beneficial, as they include tools for adding comments, making markups, and generating detailed reports directly within the model. These features ensure that communication among project stakeholders is seamless and that all feedback is centrally managed and incorporated. Moreover, Navisworks streamlines the quantity takeoff process by extracting precise material quantities from the BIM models, which aids in accurate cost estimation and budgeting.

An essential function of Navisworks in the context of infrastructure projects is its ability to integrate with scheduling software, enabling 4D simulations. These simulations visualize the construction sequence in tandem with the BIM model, providing a dynamic tool for planning and resource allocation. This phase exemplifies how Navisworks, by combining Civil 3D and Revit outputs, serves as a central hub for collaborative BIM processes, ensuring that all infrastructure elements, from road designs to utility networks and building integrations, are meticulously coordinated to avoid conflicts and ensure a smooth project execution.

4 Methodology implementations

Implementation on a Hypothetical Road Section

The methodology outlined is applied to a hypothetical road section to demonstrate its practical implementation and clarify the types of data and technical instrumentation required at each stage.

Phase One - Geospatial Analysis Using GIS and Integration with BIM: In the initial phase, comprehensive infrastructure data is crucial for effective analysis and planning. For the hypothetical road section, data collection focuses on various geotechnical aspects such as soil type, soil condition, land topography, and the characteristics of different layers beneath the road surface. This data provides a detailed understanding of the geological and environmental context of the project. GIS is utilized to illustrate and manage this geotechnical data, offering a visual representation that enhances the accuracy of the assessment and aids in the decision-making process. This phase ensures that all relevant geographic and environmental data is accurately mapped and integrated using GIS, setting a robust foundation for subsequent modeling and integration efforts.all of this kind of data will be presented using the GIS layers as shown in Fgure5.

Data Collection and Organization for Infrastructure Projects

For effective infrastructure management, particularly in the planning and design phases of road construction, it is imperative to collect and organize all relevant data into a comprehensive database. This database should encompass a wide range of data types including details about the surface layer, subsurface layers, geotechnical specifications, drainage systems, and the location and current status of various facilities.
Each element in the database should be meticulously documented to ensure that all aspects of the infrastructure are considered. This includes detailed descriptions of soil types, soil conditions, topography, material specifications, and the structural details of existing infrastructure. Additionally, information on utility networks such as water, sewage, electricity, and telecommunications should be included to provide a complete picture of the project environment. Conceptional dat presentation is shown in Figure 5. Once collected, this data is organized into a structured database that is designed to interface seamlessly with Geographic Information Systems (GIS). The integration of this database with GIS layers is crucial as it allows for advanced spatial analysis and visualization. By overlaying the structured data on GIS, stakeholders can obtain a holistic view of the project area, enhancing decision-making and planning accuracy.

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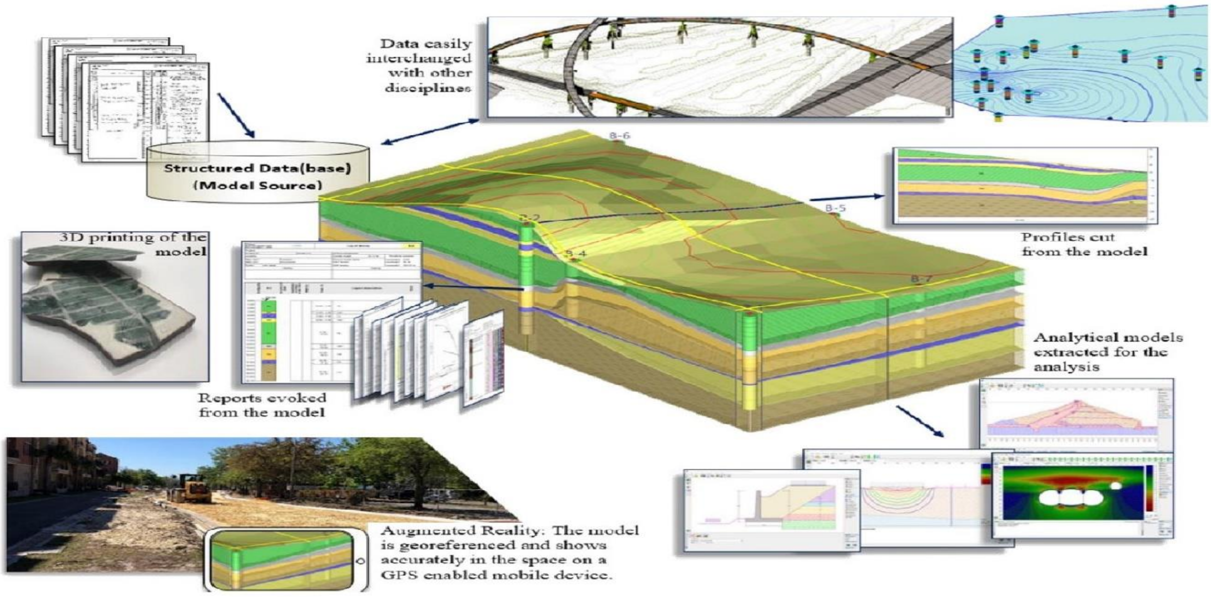

Figure 5. Infrastructure Data

Once collected, this data is organized into a structured database that is designed to interface seamlessly with Geographic Information Systems (GIS). The integration of this database with GIS layers as illustrated in Figure 6 is crucial as it allows for advanced spatial analysis and visualization. By overlaying the structured data on GIS, stakeholders can obtain a holistic view of the project area, enhancing decision-making and planning accuracy.

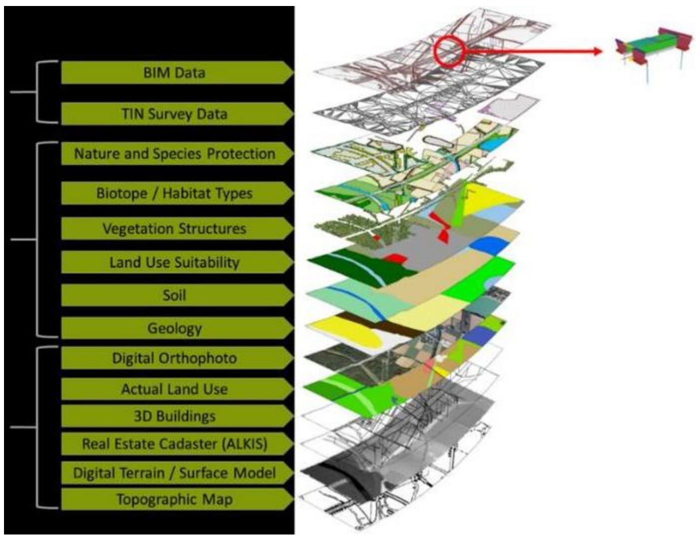

Figure 6. Conceptual GIS Infrastructures Data Layers

5 Integration with Civil 3D for Enhanced Visualization

Following the GIS integration, the data is further utilized in Civil 3D to enhance the visualization and spatial integration of the project. Civil 3D serves as a powerful tool for creating detailed digital representations of the road section, incorporating all the geotechnical and infrastructural data from the GIS-enhanced database. This step is critical as it allows engineers and designers to visualize the spatial relationships and alignments of different infrastructure elements in a three-dimensional context as illustrated in Figure 7.

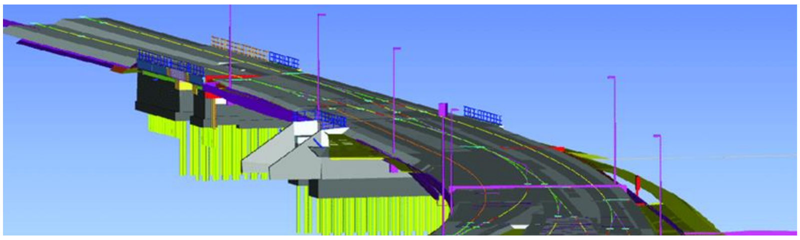

Figure 7 Road Surface resonation for Civil 3D

The use of Civil 3D enables precise modeling of the project's infrastructure, from road alignments and grading to the detailed design of drainage systems and the placement of utility networks. This visualization aids in identifying potential conflicts and allows for the adjustment of designs before physical construction begins, significantly reducing the likelihood of costly errors and rework as shown in Figure 8.

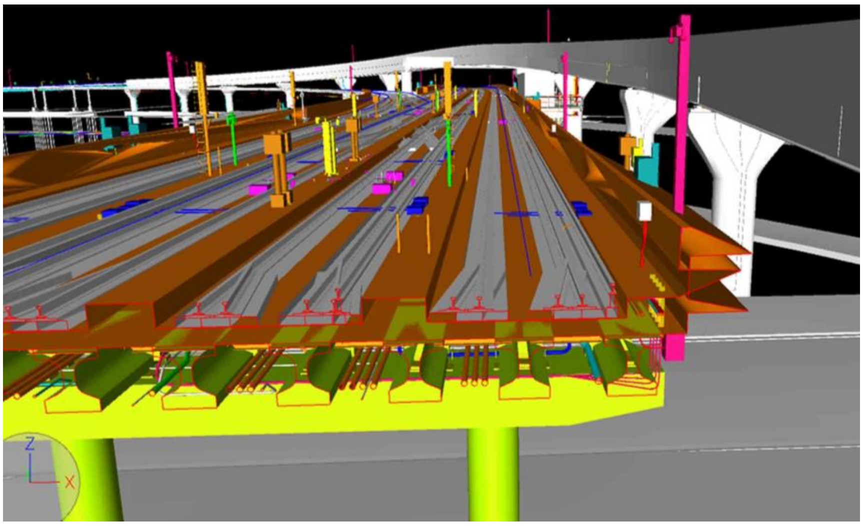

Figure 8. Integrated serveries

By organizing all infrastructure data into a comprehensive database and integrating this data with GIS and Civil 3D, the project benefits from a highly detailed and accurate planning tool. This approach not only streamlines workflow but also enhances collaboration among various stakeholders, ensuring that every phase of the infrastructure project is informed by a clear and precise understanding of all project elements.

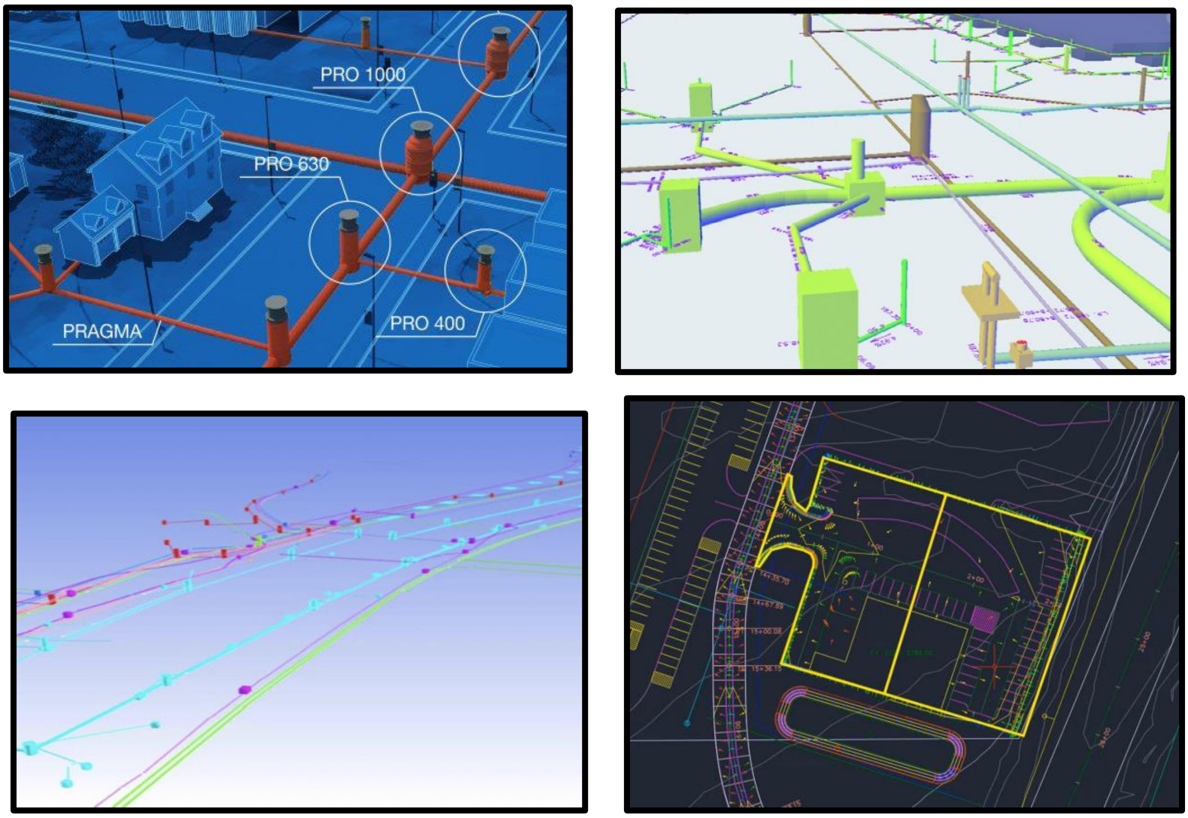

Figure 9. Civil 3D Infrastructure Representation (Road ,sewer, water and electricity)

In the transition from Civil 3D to Revit, the emphasis shifts towards enhancing visualization and rendering capabilities. While Civil 3D excels in precise engineering and design functionalities for infrastructure, Revit extends these capabilities by providing superior visualization and detailed rendering of the infrastructure models. This enhancement in visualization is not merely aesthetic but is deeply rooted in the accurate and real data sourced from municipal databases and illustrated through GIS. This integration ensures that the visual representations in Revit are both realistic and highly informative, reflecting true conditions and facilitating more informed decision-making throughout the project analysis and condition. Rivet rendering out is shown in Figure10.

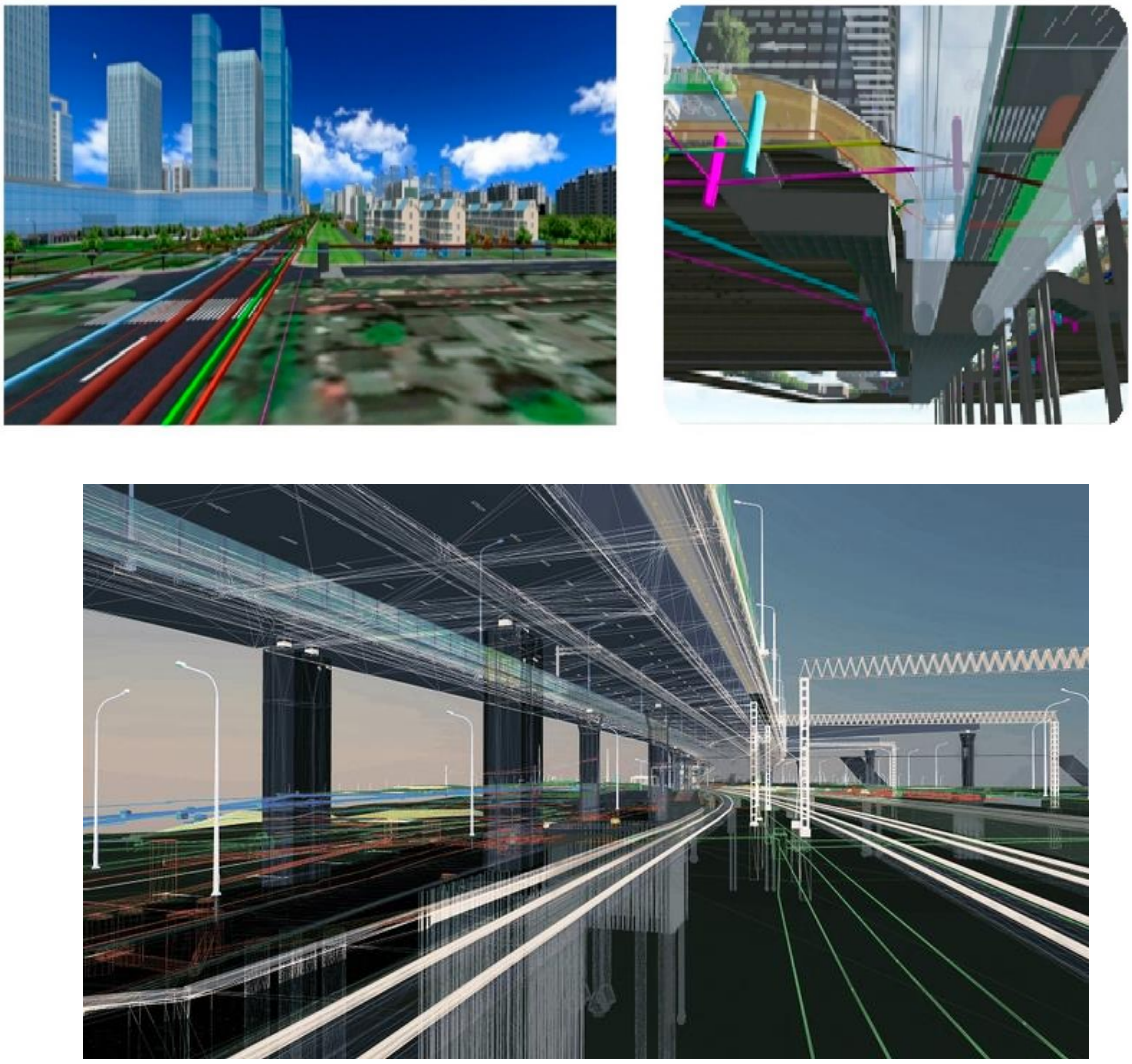

Figure 10 Rivet Rendering Output

Navisworks will create the virtual reality environment which visualizes the integrated models, allowing for dynamic navigation through the infrastructure facilities. This advanced visualization reflects the actual spatial relationships and adjacency of various components, providing decision-makers with a detailed perspective of spatial interactions among facilities. By combining models exported from Revit—such as DWG and RVT files—into a comprehensive federated model, Navisworks facilitates robust clash detection and effective coordination. This immersive environment is critical for precise intervention and strategic planning, ensuring all infrastructure elements are aligned and maintained efficiently. Navis work output is illustrated in Figures 11.

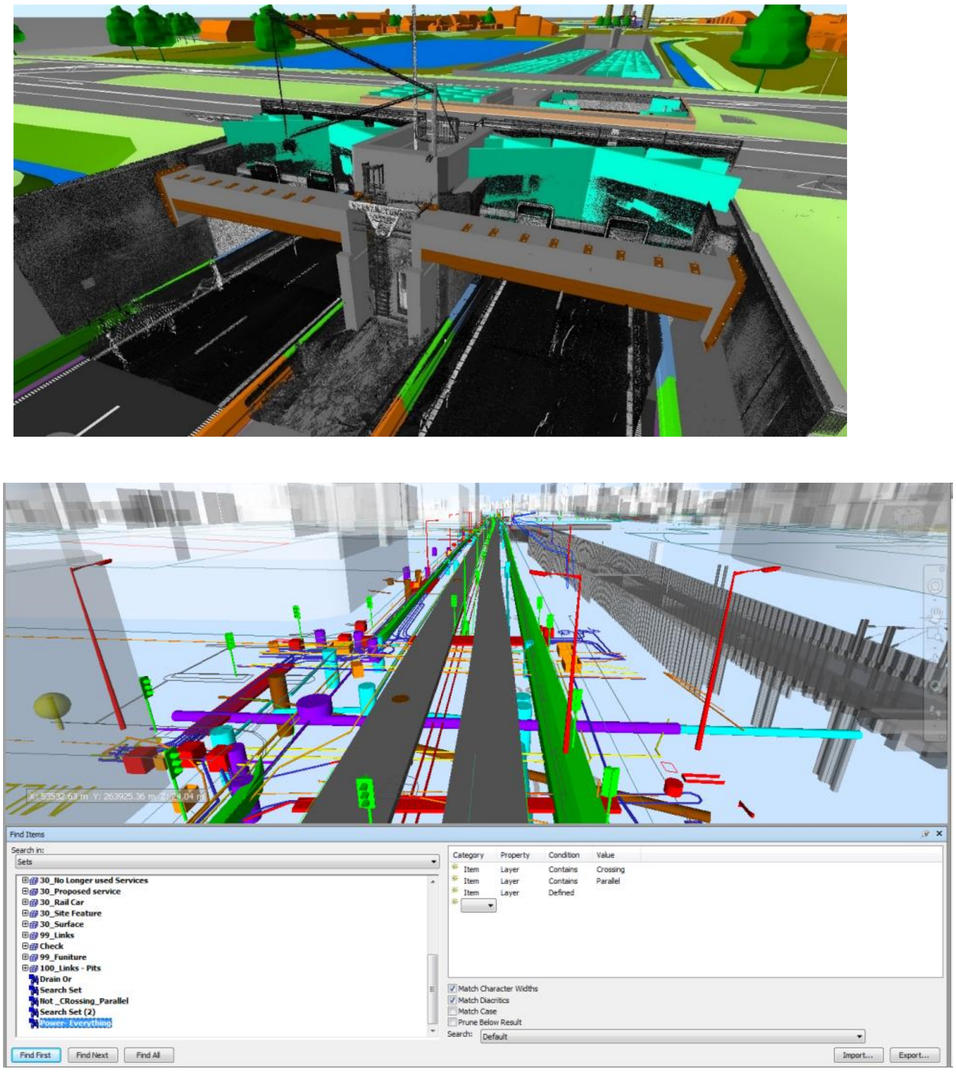

Figure 11 Navis work Navigation

6 Conclusion

This research introduces a four-phase methodology that utilizes Building Information Modeling (BIM) technologies to enhance road maintenance planning and execution. The integrated approach begins with comprehensive data collection and geospatial analysis using GIS, which sets the foundation for subsequent phases. By incorporating detailed geotechnical, structural, and environmental data into a centralized database, Phase One enables precise mapping and analysis of existing road conditions and adjacent utilities. This critical groundwork ensures that all subsequent planning and development phases are informed by accurate and comprehensive data, laying the groundwork for seamless integration and collaboration across different disciplines.

In Phase Two and Phase Three, the methodology advances by employing Civil 3D and Revit for detailed modeling and visualization. Civil 3D facilitates the design and alignment of road infrastructures, integrating them with subsurface and surface utilities to ensure that all elements are harmoniously aligned. This phase highlights the capacity for precise engineering and design modifications prior to construction, significantly reducing potential clashes and conflicts. Revit builds upon this by providing detailed 3D modeling of complex infrastructure components, allowing for enhanced clash detection and more detailed project visualization. The integration of these tools fosters a collaborative environment where changes are managed more efficiently, and project stakeholders can make informed decisions rapidly.

Finally, Phase Four leverages Navisworks to combine all individual models into a federated model that enables comprehensive visualization and project simulation. This phase is crucial for final validation of the project's design and operational planning, allowing for the simulation of construction sequences and the assessment of potential project challenges before they occur. By enabling detailed clash detection and providing tools for dynamic project review, Navisworks ensures that the road maintenance plan is not only comprehensive but also optimized for efficiency and effectiveness. This integrated BIM methodology not only enhances the precision and reliability of road maintenance projects but also significantly improves resource allocation, cost management, and project timeline adherence, ensuring successful project delivery within the complex infrastructure landscape.

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Maintenance and Asset Management: Evolution, Big Data Integration, Digital Transformation and Future Challenges in the AECO Sector

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Abstract

This paper offers a comprehensive review of Maintenance and Asset Management, tracing their evolution over the past decades and examining significant scientific advancements, specifications, and standards. A key focus is the integration of Big Data, detailing its collection, management, and transmission to enhance decision-making, predictive maintenance, and asset performance. Additionally, the lecture addresses the digital transformation of the Architecture, Engineering, Construction, and Operations (AECO) sector, discussing innovative technologies and methodologies for improved efficiency, cost reduction, and sustainability. Future challenges within the AECO sector, such as technological, operational, and management issues, will also be analyzed. The paper aims to provide professionals with the knowledge and strategies needed to tackle these challenges and leverage opportunities presented by Big Data and digital transformation, ensuring the AECO sector remains at the forefront of technological innovation and operational excellence.

KEYWORDS

Maintenance; Asset Management; AECO Sector; Big Data Integration; Digital Transformation; Future Challenges

1. INTRODUCTION

The lecture aims to offer a comprehensive review of Maintenance and Asset Management, emphasizing their origin and evolution over the past several decades. This review will not only explore the historical progression of these fields but also examine the significant scientific developments that have emerged over time. Additionally, it will explore the various applicable specifications and standards that have been established to guide best practices within the industry.

One of the key elements to be discussed is the integration of Big Data within Maintenance and Asset Management. The lecture will elaborate on the foundations and concepts related to the collection, management, and transmission of Big Data. The ability to harness large volumes of data effectively can lead to significant advancements in decision-making processes, predictive maintenance, and overall asset performance optimization.

Furthermore, the digital transformation of the Architecture, Engineering, Construction, and Operations (AECO) sector will be a major theme. This transformation involves the adoption of innovative technologies and methodologies that revolutionize traditional practices. The work will present guidelines and strategies to effectively navigate this digital shift, ensuring that the sector can leverage new tools and techniques to enhance efficiency, reduce costs, and improve sustainability.

In the end the future challenges within the AECO sector concerning Maintenance and Asset Management will be identified and analyzed. These challenges are multifaceted, encompassing technological, operational, and management aspects that are essential to the ongoing and future success of the sector.

The work presented not only shed light on the historical and current state of Maintenance and Asset Management but also provide forward-looking insights. It aims to equip professionals in the AECO sector with the knowledge and strategies needed to address upcoming challenges and to take full advantage of the opportunities presented by Big Data integration and digital transformation, ensuring that the AECO sector remains at the forefront of technological innovation and operational excellence.

2. MAINTENANCE AND ASSET MANAGEMENT

2.1. Origin and evolution

The assets of an organization, which can be tangible or intangible, are divided into different categories: financial, human, information, intangible, and physical assets. Focusing on physical assets, particularly buildings, holistic management is essential to maintain profitability and sustainability, addressing obsolescence and competitive pressure. Asset Management (AM), previously a financial term, now encompasses the management of physical assets, integrating various fields such as engineering, finance, risk management, logistics, and sustainability. AM has evolved since the 1980s and is now essential in multiple sectors, with increasing importance in engineering and maintenance (Salvado, et al., 2018; Rodrigues et al., 2015; Vale e Azevedo et. al, 2023).

Numerous studies highlight the importance of AM, from optimizing energy generation facilities to managing public infrastructures such as lighting and water networks. Specific methodologies have also been developed for different building types, such as schools. Physical asset management involves not only operation and monitoring but also adaptation to regulatory and quality requirements. Historically, AM has progressed from paper records to integration with organizational strategic objectives. Future technological integrations, like self-diagnosis and RFID, will enable efficient real-time communication of asset status, enhancing management and response to failures (AMBOK, 2014; Davies et al., 2011; Davies & Register, 2008).

Australia has undertaken public sector restructuring to enhance cost-effectiveness of assets. The holistic view of AM includes cost, risk, and performance analysis throughout asset lifecycles. Total Lifecycle Asset Management (TLAM) provides greater rigor, separating asset lifecycles into distinct phases from strategy to decommissioning, ensuring detailed planning and effective execution of AM activities (IAM, 2012).

International associations such as IPWEA, GFMAM, and ISEAM promote AM development, especially for built physical assets. Organizations are recognizing the importance of AM systems for strategic decision-making. Data repositories and control processes for maintenance activities are essential in AM. Applications like BUILDER, MAXIMO, and VFA support maintenance within AM, offering diverse tools for condition assessment, maintenance planning, and integrated activity management, representing the variety of techniques used in AM (Hassanain et al., 2003).

In summary, Physical Asset Management is essential for organizational efficiency and sustainability, involving an integrated, holistic approach to optimize costs, risks, and performance throughout asset lifecycles. The evolution of standards and technologies contributes to more effective management, aligning with organizational strategic objectives and fostering innovations in the sector (Salvado, et al., 2018; AMBOK, 2014).

Figure 1, adapted from IBM (2007), schematically illustrates the evolution of physical AM alongside corporate industrial thinking, leading to the recent ISO 55000 family of international standards.

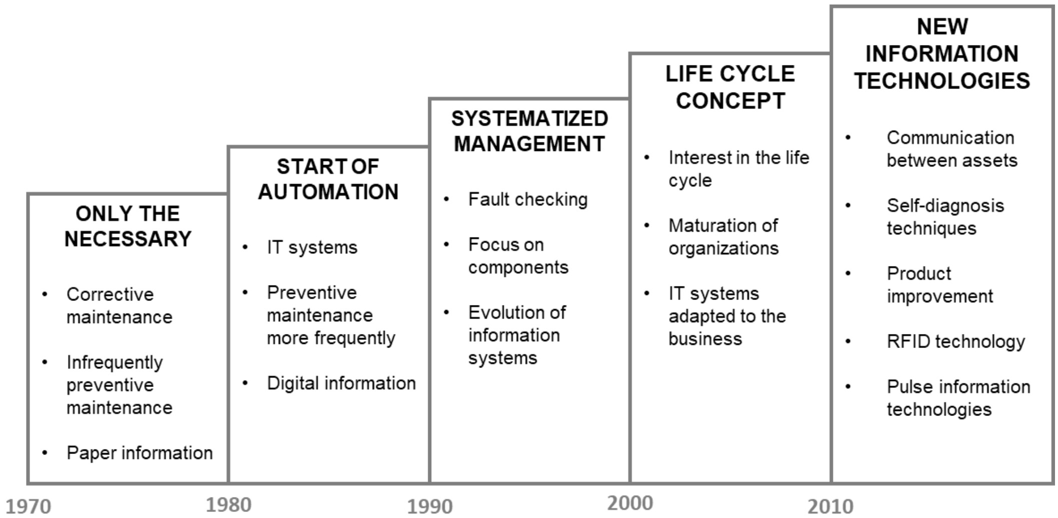

Figure 1: Asset management evolution

2.2. Specifications and standards

In 2004, the Institute of Asset Management (IAM), in partnership with the British Standards Institute (BSI), developed PAS 55 (Publicly Available Specification 55), addressing issues such as performance, risk, and expenses throughout asset lifecycles to achieve strategic organizational planning. PAS 55 serves as a guidance framework for defining an optimized AM system and is divided into: i) PAS 55-1, identifying requirements and specifications necessary to optimize AM throughout its lifecycle; and ii) PAS 55-2, a practical guide detailing orientations or tools facilitating the application of PAS 55-1 requirements. A characteristic of PAS 55 is its specification compliance guidelines, allowing asset managers flexibility in implementation.

The ISO 55000 family of international standards, published in 2014, retained key elements contributing to the popularity and success of PAS 55, including: i) aligning organizational objectives with AM strategy, goals, plans, and activities; ii) lifecycle planning of assets; iii) risk management and a risk-based decision-making framework; and iv) integration and sustainability measures such as leadership, consultation, communication, skill development, and information management. Applying PAS 55 or ISO 55000 enables organizations to gain value perception, balancing financial, environmental, and social costs, risk, and quality (Vale e Azevedo et. al, 2020).

The British standard PAS 55, the ISO 55000 international standard family, and EU Directive 2014/24 reinforced the need for developing decision support models incorporating AM components to facilitate practical application.

Related to maintenance activities, the European standard EN 16646 introduces AM as a framework for maintenance activities, along with the relationship between the organizational strategic plan and the maintenance management system. It describes the interrelationships between the maintenance process and all other AM processes, addressing the role and importance of maintenance activities within the Asset Management system throughout its lifecycle.

3. BIG DATA MANAGEMENT

Data management plays an essential role in building management activities, as it enhances the organization and standardization of data, information, and knowledge generated throughout the process. This function is vital to every organization because well-structured data management not only improves operational efficiency but also supports strategic decision-making. There is a growing recognition across industries that data is one of the most valuable resources an organization can possess. Effective data management seeks to control and leverage data assets to their fullest potential, ensuring data integrity, accessibility, and security (DAMA, 2017; Redman, 2018).

In the context of Big Data management (Figure 2), advanced techniques and tools are employed to handle and analyze vast amounts of data. This capability allows organizations to extract significant and relevant economic performance indicators, which are essential for the evolution of Maintenance and Asset Management practices. By harnessing the power of Big Data, companies can gain deeper insights into their operations, predict potential issues before they arise, and make more informed decisions that drive efficiency and growth (Kiron et. al, 2014; Marr, 2015).

Figure 2: Big Data management

To effectively address the anticipated challenges associated with managing Big Data, it may be necessary to employ specific tools designed to handle large volumes of information. These tools can provide advanced analytics capabilities, facilitate efficient data storage and retrieval, and ensure data integrity and security. By implementing such specialized tools, organizations can better navigate the complexities of Big Data management and fully leverage the insights derived from their data assets (Zikopoulos, and Eaton, 2012; Garlasu et. al, 2013).

In recent years, the National Laboratory for Civil Engineering (LNEC) has prioritized research aimed at integrating Big Data in Maintenance and Asset Management. This initiative is heavily based on the principles and practices of Big Data management. By leveraging advanced data analytics, LNEC seeks to enhance the accuracy and efficiency of performance assessments, ultimately contributing to the improvement of various processes and outcomes within the AECO industry in Portugal The research developed and under development, for Maintenance and Asset Management evolution based on Big

Data management, comprises: i) Investment decision support; ii) integrated management and building operation and maintenance; iii) Building Information Modeling (BIM) and digital transformation; iv) Life Cycle Cost Assessment and circular economy (Vale e Azevedo et. al, 2019).

Investment decision support research includes a variety of analytical methods such as cost-benefit analysis, cost-effectiveness analysis, cost-utility analysis, multicriteria analysis, sensitivity and risk analysis, and overall economic assessment. These methods aid, based on Big Data, in making informed financial decisions by evaluating the economic implications of different investment options. Integrated management and building operation and maintenance encompasses facility management, asset management, project management, and risk management, focusing on developing and implementing comprehensive strategies to ensure effective management and operation of building facilities and assets throughout their life cycle. Building Information Modeling (BIM) and digital transformation involves, firstly, the use of BIM, particularly focusing on aspects such as Industry Foundation Classes (IFC) attributes, levels of Big Data information and detail, object parameterization, and monitoring data recording. Additionally, it covers the broader scope of digital transformation, which includes the development and utilization of information and management tools throughout all phases of the construction life cycle. Life Cycle Cost Assessment and circular economy addresses the economic evaluation of the entire life cycle costs associated with construction projects and promotes the principles of circular economy, including effective waste management practices. The aim is to minimize environmental impact and enhance sustainability by rethinking resource usage and waste generation (Akadiri and Olomolaiye, 2012; Eastman et. al, 2018).

4. INTEGRATION OF DIGITAL TRANSFORMATION

With the advent of the World Wide Web, the reach, scope, scale, speed, and impacts of digitization changed dramatically. This rapid evolution led to an increased pressure on societal transformation processes as businesses, governments, and individuals alike had to adapt to an ever-changing digital landscape. Over the past decade, digitization has increasingly been utilized, not only as a technological advancement, but also as a strategic concept and rationale for a comprehensive governmental implementation of IT systems (Westerman et. al., 2014).

Digital transformation refers to the incorporation of digital technologies into every aspect of a business, fundamentally altering its operations and the way it delivers value to its customers. This expansive integration goes beyond mere technological upgrades; it requires a profound cultural shift within organizations. Companies must consistently challenge existing norms, engage in relentless experimentation, and embrace the possibility of failure as a critical aspect of the innovation process (Rogers, 2016; Vale e Azevedo et. al, 2024).

Using digital technologies, businesses can develop new processes or modify existing ones, adapt organizational cultures, and enhance customer experiences to meet the ever-evolving demands and requirements of the market. As information management migrates from paper-based systems to digital spreadsheets, and then to sophisticated smart applications, there arises a unique opportunity to reimagine and redesign these processes with advanced digital technology. This transformation is not merely about digital tools or platforms; it represents a holistic shift in how organizations operate and think. It necessitates a continuous adaptation to new digital realities, driving businesses and governments to rethink traditional methodologies and practices (Schwertner, 2017).

Essentially, digital transformation is about leveraging innovative technology to achieve greater efficiency, agility, and ultimately, superior value creation for all stakeholders involved. Through this ongoing process of digitization, organizations can not only keep pace with technological advancements but also proactively shape the future of their industries (Heinze, et al., 2018; Vale e Azevedo et. al, 2022).

The AECO industry plays a very significant role with an important impact in the global economy. This sector is responsible for the design, construction, and maintenance of the built environment, including buildings, infrastructure, and industrial facilities. Its impact is far-reaching, influencing not only economic growth but also societal development and environmental sustainability. In terms of economic contribution, the AECO sector generates substantial revenue and creates millions of jobs worldwide (European Commission, 2011; World Economic Forum, 2016).

From large-scale urban development projects to residential housing and commercial real estate, the industry sustains a wide range of businesses, from small subcontractors to multinational corporations. The ripple effect of this activity supports related industries such as manufacturing, supply chain logistics, and financial services. However, the representativeness of the sector is marked by the lack of productivity that is reflected in an inefficient image of both the process and the service delivered to the final customer (EU Regulation n.305/2011) (McKinsey Global Institute, 2017; Lucas and Aguiar, 2018).

In global terms, the AECO sector presents a medium level of digitization, although with a strong probability of rising through the implementation because of the 4th Industrial Revolution. Within the AECO sector, the construction sector is not the end of the list of sectors that implement digitization, as a process and methodology of use. The greatest difficulty to be overcome may be a transversal modernization of the sector which, as it represents the performance of different agents at different stages of the construction life cycle, implies using BIM as an integrated system for storing information (BuildingSMART International, 2017; coBuilder, 2021; CT197, 2021;).

The AECO sector is poised for a much-needed digital renovation. Confronted with persistent challenges such as inefficiencies in project execution, ongoing safety concerns, and stagnating labor productivity levels, the industry's historically slow adoption of advanced technologies has arrived at a critical juncture. Embracing digital transformation is essential and entails revamping existing processes and integrating cutting-edge tools that leverage data. This data-driven approach aims to enhance communication, boost efficiency, elevate productivity, and significantly improve safety measures across the board (BCG, 2016).

The integration of digital technologies within the AECO sector stands to position key stakeholders for considerable profitable growth within this highly competitive industry, while simultaneously addressing pressing workforce issues. However, transforming the AECO sector encompasses more than the mere implementation of state-of-the-art technologies. It involves a comprehensive overhaul that, when executed correctly, can propagate improvements throughout interconnected processes. To achieve this transformation, companies must first undertake a thorough assessment of their current operational state. This initial step is critical in identifying areas of inefficiency and pinpointing where digital tools can make the most significant impact. Following this, a forward-looking strategy must be developed to delineate the desired future state of the business. This strategic planning involves setting clear, actionable goals and outlining the necessary steps to achieve them. The final phase of the transformation process involves mapping out a detailed journey from the current state to the envisioned future (PwC, 2019; Shapiro et al., 2019)

This roadmap should incorporate a timeline for implementation, resource allocation, and milestones to track progress. By following this structured approach, businesses in the AECO sector can ensure a smoother transition and maximize the benefits of digital transformation. Therefore, the digital renovation of the AECO sector promises to revolutionize the industry. Enhanced data utilization will lead to better decision-making, streamlined operations, and improved collaboration among all stakeholders. The focus on digital transformation is not just a technological upgrade but a strategic move towards a more efficient, productive, and safe working environment, fostering sustainable growth and innovation across the entire industry (Deloitte, 2020).

Digital transformation goes far beyond digitalizing analog functions. It enables a fundamental shift in how to operate so that it can compete in a digital world. Figure 3 presents the areas of transformation that are ultimately enabled by end-user adoption (Shapiro et al., 2019): i) Digital Business (to enable growth); ii) Digital Process (to improve efficiency and profitability); and iii) Digital Backbone (to facilitate usability for processes needs).

Figure 3: Digital transformation, adapted from (Shapiro et al., 2019)

5. FUTURE CHALLENGES

Based on the previous sections, some future challenges aligned with Maintenance and Asset Management within the AECO sector are identified, namely: i) Integration of Big Data; ii) Data Security and Privacy; iii) Digital Transformation; iv) Standardization of Practices; v) Predictive Maintenance Implementation; vi) Sustainability and Environmental Impact; vii) Cost Management: viii) Workforce Training and Adaptation; ix) Interoperability of Systems; x) Change Management. The main strategies and actions to overcome these challenges are described in Table 1

Table 1: Challenges, strategies and actions for Management and Asset Management future evolution

CHALLENGES		STRATEGIES	ACTIONS
Integration of Big Data	Effectively collecting, managing, and transmitting large volumes of data to enhance decision-making and predictive maintenance	Implement a Robust Data Management and Analytics Platform	• Upgrade and Standardize Data Infrastructure • Advanced Analytics ToolsEnhance • Workforce Skills and Data Literacy
Data Security and Privacy	Ensuring the security and privacy of sensitive data collected and used in Maintenance and Asset Management processes	Implement a Comprehensive Cybersecurity Framework	• Adopt Advanced Encryption and Access Control Measures • Conduct Regular Security Audits and Vulnerability Assessments • Develop and Enforce Data Privacy Policies
Digital Transformation	Navigating the shift from traditional practices to innovative technologies and methodologies in the AECO sector	Develop a Clear and Phased Digital Transformation Roadmap	• Conduct a Comprehensive Needs Assessment • Implement Pilot Projects and Scale Gradually • Invest in Employee Training and Change Management
Standardization of Practices	Establishing and adhering to universal specifications and standards for best practices in Maintenance and Asset Management	Establish and Implement Industry-Aligned Best Practices and Standards	• Collaborate with Industry Bodies and Standards Organizations • Develop Comprehensive Internal Guidelines • Conduct Regular Training and Audits
Predictive Maintenance Implementation	Developing and implementing predictive maintenance strategies using advanced analytics and data science techniques	Integrate Advanced Predictive Analytics Tools into Maintenance Processes	• Invest in IoT and Sensor Technologies • Implement Predictive Analytics Software • Train Maintenance Teams on Predictive Maintenance Techniques
Sustainability and Environmental Impact	Incorporating sustainable practices and reducing the environmental footprint of Maintenance and Asset Management activities	Implement a Comprehensive Sustainability Program	• Adopt Energy-Efficient Technologies • Develop and Enforce Sustainable Practices • Monitor and Report on Sustainability Metrics
Cost Management	Balancing the cost of implementing new technologies and methodologies with the potential savings and efficiency gains	Implement a Robust Budgeting and Monitoring System	• Develop Detailed Budgets for Each Project or Department • Implement Real-Time Expense Tracking Tools • Conduct Regular Financial Reviews and Audits
Workforce Training and Adaptation	Ensuring that the workforce is adequately trained to handle new tools, technologies, and methodologies introduced by digital transformation	Implement a Continuous Learning and Development Program	• Create Personalized Training Plans • Leverage Technology for On-Demand Learning • Establish a Mentorship and Peer Learning Program
Interoperability of Systems	Ensuring seamless integration and communication between various digital systems and platforms used in Maintenance and Asset Management	Adopt a Standardized Integration Framework	• Implement API-First Development • Utilize Middleware Solutions • Establish Data Standards and Protocols
Change Management	Managing organizational change to adopt new practices and technologies while maintaining operational continuity and stakeholder engagement	Develop and Implement a Comprehensive Change Management Plan	• Engage Stakeholders Early and Often • Provide Comprehensive Training and Support • Monitor Progress and Adapt as Needed

6. FINAL REMARKS

This paper offers an in-depth review of maintenance and asset management, tracing their evolution and highlighting scientific advancements. It emphasizes the integration of Big Data and digital transformation within the AECO sector, providing practical guidelines for leveraging these technologies to enhance efficiency and sustainability. The work addresses future challenges, equipping professionals with strategies to navigate changes and capitalize on emerging opportunities, ensuring the AECO sector remains at the forefront of innovation and operational excellence.

The AECO sector must proactively address numerous future challenges in maintenance and asset management to ensure continued progress and competitiveness. Key areas requiring attention include the integration of Big Data, which promises significant advancements in decision-making and predictive maintenance, but also necessitates robust data security and privacy measures. The ongoing digital transformation demands not only the adoption of new technologies but also the standardization of practices across the industry. This standardization will facilitate smoother implementation of predictive maintenance techniques, further enhancing operational efficiency and asset longevity. Additionally, the sector must prioritize sustainability and environmental impact to meet regulatory requirements and societal expectations.

Furthermore, effective cost management remains essential, requiring adequate budgeting and continuous financial monitoring. Workforce training and adaptation are essential to equip employees with the skills needed to navigate new technologies and methodologies. Ensuring interoperability of systems will foster seamless communication and data exchange, enhancing overall efficiency. In conclusion, adept change management strategies will be vital in guiding organizations through these transitions, minimizing resistance and maximizing engagement. By addressing these challenges through targeted strategies and actions, the AECO sector can drive innovation, improve operational excellence, and maintain a sustainable trajectory, securing its place at the forefront of industry advancements.

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