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Revolutionizing Building Maintenance: Development and Efficiency Enhancement Through Technology Advancement

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Abstract: *This study presents the advancements in technology for building maintenance management, covering the timeline from 1900 to 2019. The aim of this study is to explore and highlight the advancements in technology that have revolutionized building maintenance management. The objectives of this study are to chronicle the technological evolution in building maintenance, highlighting how diverse technologies have improved efficiency, effectiveness, and precision in this field, while also shedding light on the profound transformative influence of technology on building maintenance practices. It emphasises key developments, including engineering technology, computer-assisted maintenance, automation, visualisation technology, barcoding systems, building information modelling (BIM), robotics, augmented reality, small aerial vehicle-based image acquisition, and machine learning algorithms. These technologies are recognised for their role in enhancing efficiency, effectiveness, and accuracy in building maintenance. The methodology used in this study involves a historical approach, tracking the development of technology in building maintenance from 1900 to 2019. It also involves detailed descriptions of the various technologies and their significance in building maintenance practices. Their applications in improving processes, identifying defects, optimizing energy efficiency, and supporting decision-making are highlighted. In summary, this study provides comprehensive insights into the continuous advancements in technology that have revolutionized building maintenance management. It offers a comprehensive understanding of the various technologies utilized in the field.*

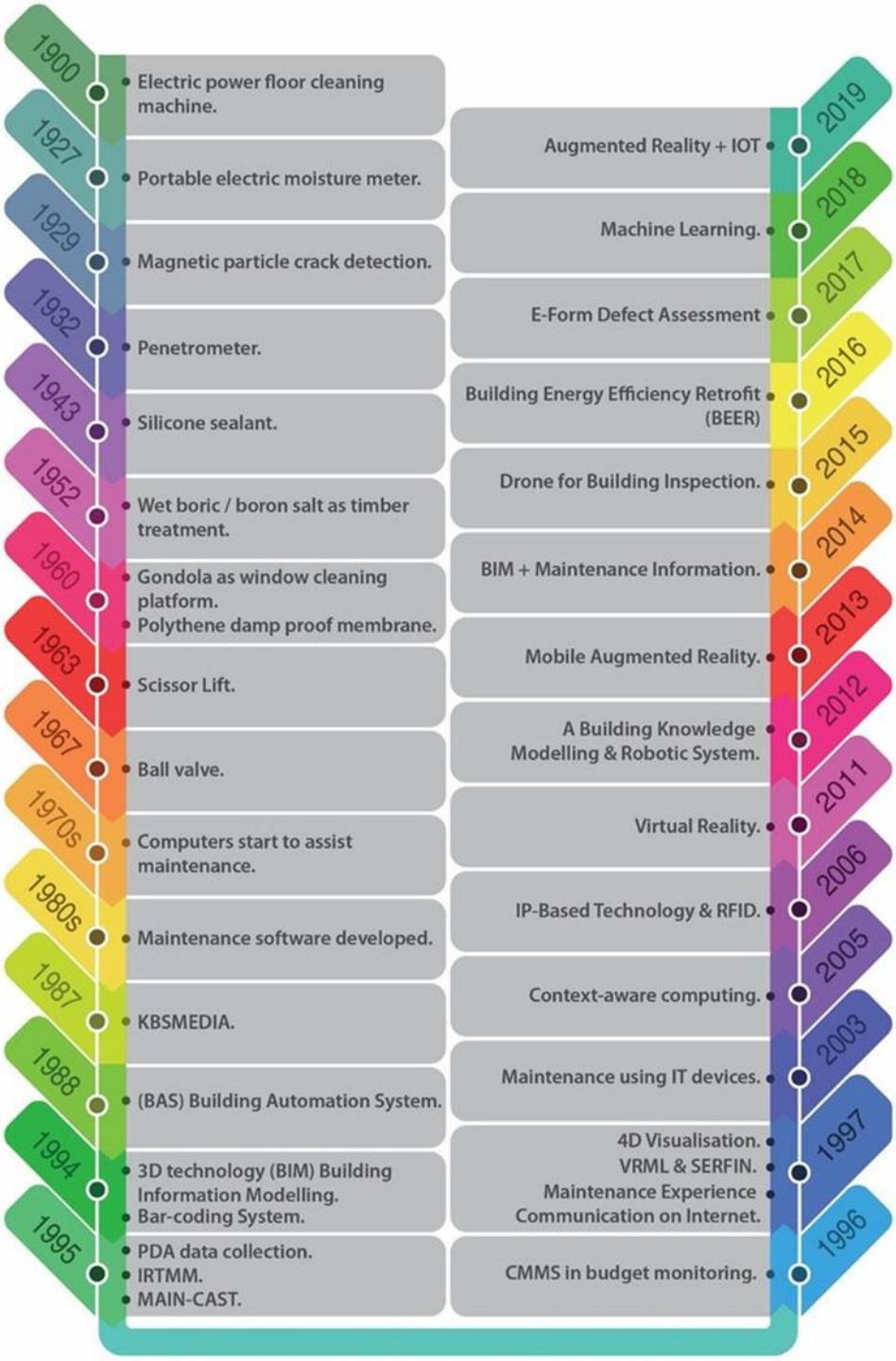
Keywords: Building maintenance, Technology advancements, Efficiency enhancement, Technology integration and Revolutionizing building maintenance

1. Introduction

The current technological advancements in supporting building maintenance management are being explored in this study. It highlights the evolution of technology throughout history and its impact on various aspects of building maintenance. The timeline of technology development in building maintenance from 1900 to 2019 is presented, demonstrating the progression of engineering and material technology, computer-assisted maintenance, automation,

visualization technology, barcoding systems, building information modelling (BIM), robotic technology, augmented reality, small aerial vehicle-based image acquisition, and machine learning algorithms. Each technology is discussed in detail, emphasizing its significance and contributions to building maintenance practices. This study aims to provide insights into the continuous advancements in technology that have revolutionized building maintenance management and enhanced efficiency, effectiveness, and accuracy in maintaining buildings and assets. The three objectives of this study are to track the timeline of technology development in building maintenance, discuss and emphasise the role of various technologies in enhancing efficiency, effectiveness, and accuracy in building maintenance, and provide insights into the transformative impact of technology on the field of building maintenance.

Table 1: Timeline for Technology Development in Building Maintenance (1900 – 2019)



For the first seventy years (1900 – 1970), building maintenance covers the aspect of engineering and materials technology. The computer starts to assist building maintenance works in 1970. The internet getting involves with the computer in the building maintenance work in late 1990. At the same time, the collaboration with other devices happened in early 2000 with involvement, virtual reality camera, RFID tools, to the use of robots in maintaining the buildings. In 2010, Building Information Modelling (BIM) became parts of building maintenance practices; it helps mainly in defect assessment and energy efficiency areas. The technology involved in building maintenance will never stop, as recently added: the intelligent system of machine learning and the internet of things (IoT). The following section explains the technology development in building maintenance started from 1900 to 2019.

Engineering and Material Technology Innovation Involves in Building Maintenance

Engineering and material technology plays essential roles in maintenance practices in the early years. The development on engineering aspects in maintenance was never stopped as improvement been made from time to time. In 1900, powered vacuum cleaners using suction for building cleaning work were invented independently by British engineer Hubert Cecil Booth and American inventor David T. Kenney (Gantz, 2012). In 1927 the first portable electric wood moisture meters with a "blinker-type" meter were created. In its operation related to building maintenance practices, it detects the moisture of a subject. A meter had a neon lamp attached to a capacitor, which was in contact with the wood. The capacitor would absorb the charge running through the wood. When the capacitor was fully charged, the neon lamp would briefly light up (Morgan, 2021). The industrial application of magnetic particle crack detection was developed by Victor de Forest and Foster Doane in 1929 (Deutsch, 2007) The crack formation in the building often began at the surface, and then the crack grew into the material due to stress concentrations at the crack tip. Cracks are the most crucial defect type in maintenance and must be eliminated by grinding out the crack or scrapping the completed component. The first static cone penetrometer test was made in 1932—1937 by P. Barentsen, who developed a sleeve-type apparatus (Sanglerat, 1972). This tool provides valuable information about granular and cohesive materials in a building. The Chemical engineering sector started contributing to building maintenance practice in 1943 when General Electric invented silicone sealant (Chase, 1998). They provided a water-resistant seal that maintained a stronghold against harsh weather conditions. For the same reasons, silicone sealer was often used for automobiles, appliances, and sealing cables and sensors in electronic devices. In the wood treatment-related technology, the wet boric or boron salts timber treatments were first introduced in 1952 – before that, native timber and some of the first radiate pine framing were used untreated (Standards NZ, 2013). This material helps to prolong the lifespan of wood in a building. In the mid-1960s, polythene damp- proof membranes were introduced and became an accepted form of damp proofing. This barrier was usually laid below the concrete slab to avoid leaking in a building, especially in the toilet area (the University of the West of England, 2009). Gondola was used as part of a window cleaning machine created in 1960. This system performs the cleaning operation by adhering to the multi-story building walls. (Hester, 2019) Charles Larson (1963) from the USA first patented the scissor lift in 1963, but he did not invent it; John W Parker of California invented it. The scissor lift today being used in maintenance work, mainly in a building that has high ceiling. The earliest ball valves were commercially available around 1967 (Xu, 2017). A ball valve is a shut-off valve in the water tank of the building that controls the flow of a liquid using a rotary ball having a bore. The development of engineering and material technology will never stop, and its combination with other technologies like the computer and IT creates a new dimension in maintenance practices.

Computer Assist Building Maintenance

Computers have been used to assist the maintenance management process since the early 1970s, and by the mid-1980s, a substantial number of maintenance organizations were using software developed for large mainframe computer systems (Pettit, 1983). The software was normally designed around a central computerized database into which the maintenance and repair information was recorded. The information was then manipulated to produce the work schedules and job orders. Report generators allowed the work-in-progress to be monitored and statistical management information to be produced. During the late 1980s, a range of powerful and sophisticated microcomputers was developed. These systems were designed to be personal productivity tools, and they quickly became commonplace in many organizations. Consequently, many maintenance managers had unrestricted access to the complicated computer systems for the first time (Atkin, 1987). The result of this increased access was the demand for more microcomputer-based maintenance management solutions. To satisfy these demands, many software houses had developed property/maintenance management packages. These packages, although similar in concept to the mainframe systems of the 1970s, were more comprehensive, using relational database development tools to link far more aspects of the maintenance (and building management) process as supported by (Bates, 1987; Jones & Collis, 1996; Spedding, 1987). Studies on computerized maintenance management systems (CMMS) showed that budget monitoring and analysis was the most popular computerized maintenance management activity, followed by repair scheduling, control of maintenance contracts and condition surveys (Jones & Collis, 1996). The Department of Structural Engineering of Lund University had built KBSMEDIA (knowledge-based systems-media) as a demonstrator system used to capture, test, and transfer the ideas among the system end-users in the building process system builders/tool makers. Demonstrator systems from this project were concerned with 'Building Maintenance ' and 'Material and Vendor Information' (Christiansson, 1997). The third supporting technology is automation in building maintenance, which will be explained further in the next section.

Automation in Building Maintenance

It has been suggested that a building automation system (BAS) is the automatic operation of building systems by sensors and controllers that were integrated into various ways to form a BAS. BASs were usually used to perform the following tasks; 1) To optimise system start-up and performance and control/monitor systems. 2) To reduce the risk of the breakdown of building services. 3) To increase the interaction of mechanical subsystems within a building. 4) To prevent deterioration of the internal environment provided by building services. 5) To increase the reliability of systems and services and 6) To reduce energy, time and operating costs (Eyke, 1988). The following section will discuss the next technological advancement that supported building maintenance management, which is the visualisation technology in building maintenance.

Visualisation Technology in Building Maintenance

3D visualization technology was applied to visualize facilities targeted for Maintenance Management work, including the spatial navigation systems established for museums, campuses, and cities. However, the functionality of these visualisation systems was limited to navigating an overview of a facility only. In 1994, it was proposed that the Building Maintenance (BM) knowledge should be represented in various forms using a range of Artificial Intelligence (AI) representational formalisms such as frames, objects, predicates, semantic nets and rules. For the proposed system, the information on projects and elements already stored by the Building Information Modelling (BIM) module was retrieved to identify

all the technical and maintenance information of the BM case, including any information on the building elements related to the maintained element. Moving to the following subsection, the bar-coding system in building maintenance will be elaborated in the scope of this study.

Bar-coding, Intelligent Real-Time Maintenance and Building Element Maintenance Forecast Valuations

In 1994, the material management system in maintenance work was improved through the bar-coding system (Baldwin, 1994). In 1995, a PDA-based data collection application with the combination of a bar-coding system was designed for maintenance inspection tasks. The Centre for Integrated Facility Engineering (CIFE) at Stanford University had developed the Intelligent Real-Time Maintenance Management (IRTMM) System (Nathwani & Shroff, 1995). The system's objective was to perform value-based plant maintenance as needed; this idea was developed by (Kunz et al., 1995).

MAINtenance ForeCASTing in an Integrated Construction Environment (MAIN-CAST) was developed and proposed to forecast the building element maintenance of a project as part of a fully integrated environment. MAINCAST was aimed to generate the building element maintenance forecast valuations within a developed integrated construction environment prototype - the Simultaneous Prototyping for an Integrated Construction Environment or SPACE (Alshawi & Faraj, 1995). The following section will review the available literature regarding virtual reality and interactive transmission of information in building maintenance related to this study.

Virtual Reality and Interactive Transmission of Information Related to Building Maintenance

The concept of 4D visualisation in building maintenance was introduced in 1997; it reflected the state of a building through time by focusing on three aspects of building maintenance - lighting, paint and carpets (Rad & Khosrowshahi, 1997). A model had been proposed to simulate visualisation, which can be viewed by an appropriate Virtual Reality Modelling Language (VRML) browser at any given point in the lifetime of the items, including the design. The simulator will draw the information from the design object analyser in conjunction with the maintenance schedule analyser (Fairbairn & Parsley,1997). The SERFIN Project was developed at the KBS-Media Lab, Lund University, to provide the knowledge on handling the facilities management, which aimed to: (a) identify and capture problems that arose in connection with the technical maintenance of buildings; (b) ease the problem-solution process occurred during the maintenance of the buildings, making it more effective; and (c) make the experiences from technical maintenance readily available and accessible in time and space. SERFIN is currently based on the web pages on the Internet together with text queries (Christiansson, 1997). A Virtual Reality model to support the maintenance of walls in a building was developed within a research project in 2011. It enabled the visual and interactive transmission of information related to the physical behaviour of the elements to be defined as functions of time (Sampaio, 2012). Another supporting technology that will be discussed in the next section is building information modelling in building maintenance.

Building Information Modelling in Building Maintenance

An integrated case-based reasoning Building Information Modelling (BIM) system for building maintenance, as an approach to establish the transformation from ‘Building Information Modelling’ to ‘Building Knowledge Modelling’ was developed in 2012. The system could help the maintenance teams learn from the previous experience and trace the entire history of a building element and all affected elements in the previous maintenance operations for any

maintenance cases. While the developed system was more concerned with the information/knowledge capture and retrieval, the system's efficiency could be improved by the automation of data captured using technologies such as RFID, which was a part of the current development of this system (Arayici et al., 2012). The implementation of ICT tools (electronic form) resulted in better improvement as it led to the tremendous saving in the budget, time planning, and precise data in handling the defect diagnosis and control. The study conducted in 2017 also suggested acceptable practices through BIM implementation, which could reduce the repetition of the defect in the design specification used and construction practice for the building structure and facility (Ismail, 2017). BIM-Based Augmented Reality Maintenance System (BARMS) provided an illumination function in darkness, showing a safe maintenance route, projecting BIM models, confirming relative locations, and illustrating maintenance using animation. A study conducted in 2019 also shown that BARMS were very effective when working outdoors at night or in similar indoor low light situations by seamlessly integrating the existing conditions with the overall scope of the setting and using the readily available smartphone illumination function (Diao & Shih, 2019). In 2014, the Department of Architectural Engineering, Ajou University, Suwon, South Korea, revealed that checking information, material information, equipment information, supplier information, and maintenance history information should be embedded in the BIM model in order to effectively give feedback to the operation and maintenance stage in of a building. Thus, the study had proposed a novel data format structure that can effectively link the 3D/BIM object with the maintenance data (Ahn & Cha, 2014). The next technology that supported building maintenance management is robotic technology, which will be elaborated on further in the next section.

Robotic Technology and Augmented Reality on Mobile Devices Involves in Building Maintenance

A building maintenance robot system based on built-in guide rails was developed in 2012. In this system, a vertical climbing robot adopting an inch-worm mechanism used a hook mechanism to perform the vertical climbing work of a horizontally moving robot by using a Compact Docking mechanism. In addition, a material transportation system helped the horizontal robot convey the materials needed for maintenance to the building by using the vertical climbing robot (Moon et al., 2012). In 2013, a study was carried out by the Building Engineering students of Universitat Politècnica de Catalunya Barcelona Tech on the feasibility of using Augmented Reality on mobile devices to provide additional information for a better understanding of the building, thus contributing to greater efficiency in construction processes, rehabilitation, or building maintenance (Sánchez Riera et al., 2013).

Small Aerial Vehicle-Based Image Acquisition System and Machine Learning Algorithms in Building Maintenance

In 2015 a study was conducted to specifically develop the small aerial vehicle- based Image acquisition system to inspect structures aiming to identify the cracks of the building. It resulted in an uncrewed aerial vehicle (or drone) which specifically required to inspect the facilities in order to deal with the limited access of an inspector, in order to examine multiple structures and to confirm whether the inspected areas were damaged in each season or daily time frame (Choi & Kim, 2015). In 2018, a study on machine learning provided new opportunities within the facility management domain to improve the quality of information collected through online work orders. It also improved the reporting systems by automatically classifying work orders and prompting building occupants with appropriate facility management team developed

questions in real-time to gather the required specific information in a structured form (McArthur et al., 2018).

2. Methodology and Analysis of the Study

The methodology used in this study involves a historical approach, tracking the development of technology in building maintenance from 1900 to 2019. It also involves detailed descriptions of the various technologies and their significance in building maintenance practices.

The analysis in this study covers the historical evolution of technology in building maintenance, categorizing it into different eras. The analysis highlights key developments in engineering and materials technology, computer-assisted maintenance, automation, visualization technology, barcoding systems, building information modelling (BIM), robotics, augmented reality, small aerial vehicle-based image acquisition, and machine learning algorithms. The study emphasizes the significance of these technologies in improving processes, identifying defects, optimizing energy efficiency, and supporting decision-making in building maintenance.

3. Conclusion

This study explores building maintenance management technology and its evolution from 1900 to 2019. Advancements in engineering, materials, computer-assisted maintenance, automation, visualization, barcoding, BIM, robotics, augmented reality, and machine learning are highlighted. Early developments included powered vacuum cleaners, wood moisture meters, and magnetic particle crack detection. Silicone sealants and damp-proof membranes were introduced for improved maintenance. In the 1970s, computerized systems for maintenance management emerged, followed by microcomputer-based solutions in the 1980s. CMMS facilitated tasks like budget monitoring and repair scheduling. Knowledge-based systems were explored. Automation, visualization technology, and BAS optimized system performance and aided maintenance work. Barcoding improved material management, while BIM systems captured maintenance-related information. Augmented reality and mobile devices enhanced understanding of buildings. Robotic technology and small aerial vehicles were used for inspections. Machine learning algorithms improved information quality. The study does not explicitly provide recommendations; however, based on the analysis, some implicit recommendations can be inferred. Thus, building maintenance professionals should stay updated on the latest technological advancements to improve efficiency and effectiveness. Organizations involved in building maintenance should consider adopting technologies like BIM, robotics, and machine learning to enhance their maintenance practices. Further research and development in the field of building maintenance technology should be encouraged to drive continuous improvement. Overall, this study provides valuable insights into how technology has transformed the field of building maintenance management, enhancing efficiency, effectiveness, and accuracy in maintaining buildings and assets.

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