Using Point Clouds for Creating a Digital Model of an Existing Building and Its Application in Mechanical Systems Maintenance-Systematic Review

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Abstract

This research addresses the challenge of creating accurate 3D BIM models for existing buildings using laser scanning and point cloud technologies, enabling effective documentation, management, and use in mechanical system maintenance. The study also aims to assess the integration effectiveness of these technologies with BIM software in facility management, shedding light on challenges related to workforce and resource shortages for their implementation. It emphasizes the importance of raising awareness about the benefits of using point clouds and their applications to enhance maintenance operations and building sustainability, thereby enhancing the ability to make informed technical and economic decisions to achieve comprehensive maintenance goals.

Keywords: BIM (Building Information Modeling); Laser scanning; Point cloud; Facility management; Mechanical system maintenance;3D modeling; Integration with BIM software; Building documentation; Sustainability in buildings; Technical and economic decisions

1. Introduction

In the realm of modern architecture, creating three-dimensional BIM models for existing buildings poses a significant technical challenge [1]. The use of two-dimensional CAD drawings imposes limitations on documenting, managing, and maintaining these buildings, especially concerning detailed information. Therefore, this research aims to utilize advanced techniques such as laser scanning and point cloud integration with BIM software to develop accurate three-dimensional models. These models serve as comprehensive databases enabling efficient building management and effective use in mechanical systems maintenance. The research also seeks to explore the effectiveness of these technologies in facility management and highlight challenges related to the shortage of personnel and resources required for their full implementation. From this, we can pose the following questions: How effective is the integration of laser scanning technology with BIM software in facility management? What is the impact of the shortage of personnel and resources required to implement this technology?

2. Literature Review

Building Information Modeling (BIM) is a technology used for creating and managing building and facility data, providing an integrated approach to planning, design, construction, and management of buildings and assets. The fundamental concept of BIM involves creating a detailed three-dimensional digital model of a building, incorporating information about each building element such as materials, dimensions, specifications, and spatial relationships among various elements. This model serves as

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more than just a visual representation; it is a rich information database that can be utilized throughout the building's lifecycle, from initial design through construction, operation, and maintenance.
The benefits of BIM [2] are manifold: enhancing collaboration among stakeholders in a construction project, improving design quality, facilitating better project management, enhancing construction efficiency, and facilitating maintenance and operation. BIM is not merely a software tool; it represents a comprehensive process involving appropriate software, proper training, and a shift in work culture.
Point Cloud, on the other hand, represents a massive collection of three-dimensional points that depict the surface of a specific object or environment [3]. It finds applications in various fields such as geographic mapping, industrial design, robotics, medical imaging, virtual and augmented reality, architectural design, and more. In a Point Cloud environment, various three-dimensional technologies and tools are utilized, including sensors, digital cameras, laser scanning devices, alongside processing and analysis software. These tools assist in converting three-dimensional points into useful information, involving techniques like noise filtering, object segmentation, feature extraction, and 3D model design.
The integration of Building Information Modeling (BIM) with technologies like Point Cloud represents a significant advancement in the construction industry. This integration allows for accurate as-built documentation, improved project visualization, and streamlined workflows from design through facility management. The synergy between BIM and Point Cloud technologies[4] not only enhances efficiency but also ensures accuracy and reliability in construction projects. This literature review underscores the transformative impact of BIM and Point Cloud technologies in the construction sector, emphasizing their role in enhancing collaboration, design quality, project management, construction efficiency, and facility maintenance [5].

3. Methodology

Bibliometric Data Collection:
The Google Scholar search engine was utilized to find research and scientific papers related to the research topic [6, 7]. Initially, a broad search was conducted using the term "Point Cloud," which yielded 4,370,000 results. Due to the high number of results, the search was refined using "Point-Cloud," narrowing it down to 492,000 results. Further refinement involved using "Point-Cloud" as a keyword in the article titles and adding "Mechanical" as an additional keyword, resulting in 23 relevant findings. To classify and organize the results, the "Publish or Perish" software was employed, which presented the results sorted by citation count, researcher names, and publishers. This initial evaluation will aid in identifying important research papers that will be included in the final analysis of the study. Through this systematic process, comprehensive and organized data collection is ensured, contributing to achieving the research objectives and enhancing understanding of current knowledge related to building information modelling and point cloud techniques [8, 9].

Content Analysis Data Collection:
The qualitative analysis data was meticulously and methodically collected, targeting sources and studies addressing the use of point cloud technology in mechanical applications [10]. Key variables were identified, and textual data was gathered from selected studies, including direct quotations and detailed analytical results regarding the utilization of point clouds in analyzing mechanical systems and components [11, 12]. After organizing and deeply analyzing the data to extract patterns and trends, a deeper understanding of the benefits of this technology in additive manufacturing and mechanical systems maintenance was achieved. Consequently, the aggregated data yielded concrete results that contribute to providing new and valuable insights into the applications of point clouds in the mechanical context, thereby enhancing the value and practical applications of the research.

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Data Analysis:

Bibliometric Analysis:

Table 1: Top Cited Authors

Cite	Authors
39	Y Wang, S Zhang, B Wan, W He, X Bai
17	HB Adallah, JJ Orteu, B Dolives…
16	W Shen, H Song, HY Feng
12	HB Abdallah, JJ Orteu, I Jovančević…
8	Y Yang, X Liu, C Kan
8	S Tsugawa, K Teratsuji, F Okura, K Noshita, M Tateno…

The results presented in the table indicate that the most cited studies and research focus on several diverse research teams, reflecting broad interest in point cloud technology and its applications in the mechanical context. It is noted that highly cited research includes prominent researchers in this field, highlighting the importance of this technology and its contributions to advancing industrial processes and mechanical system maintenance.

Table 2: Most Productive Authors

Article Count	Authors
818	W Shen
237	JJ Orteu
171	W He
155	HY Feng
87	S Zhang

The numbers in the table indicate that W Shen has the highest number of articles, totaling 818 articles, followed by JJ Orteu with 237 articles, then W He with 171 articles, HY Feng with 155 articles, and finally S Zhang with 87 articles.

Table 3: Top Cited Papers

Cite	Title
39	Point cloud and visual feature-based tracking method for an augmented reality-aided mechanical assembly system
17	3D point cloud analysis for automatic inspection of aeronautical mechanical assemblies
16	A point cloud simplification algorithm for mechanical part inspection
12	Three-dimensional point cloud analysis for automatic inspection of complex aeronautical mechanical assemblies

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8	Point cloud based online detection of geometric defects for the certification of additively manufactured mechanical metamaterials
8	Exploring the mechanical and morphological rationality of tree branch structure based on 3D point cloud analysis and the finite element method

Table 4: Top Cited Publisher

Cite	Publisher
39	Springer
17	spiedigitallibrary.org
16	Springer
12	spiedigitallibrary.org
8	Elsevier
8	nature.com

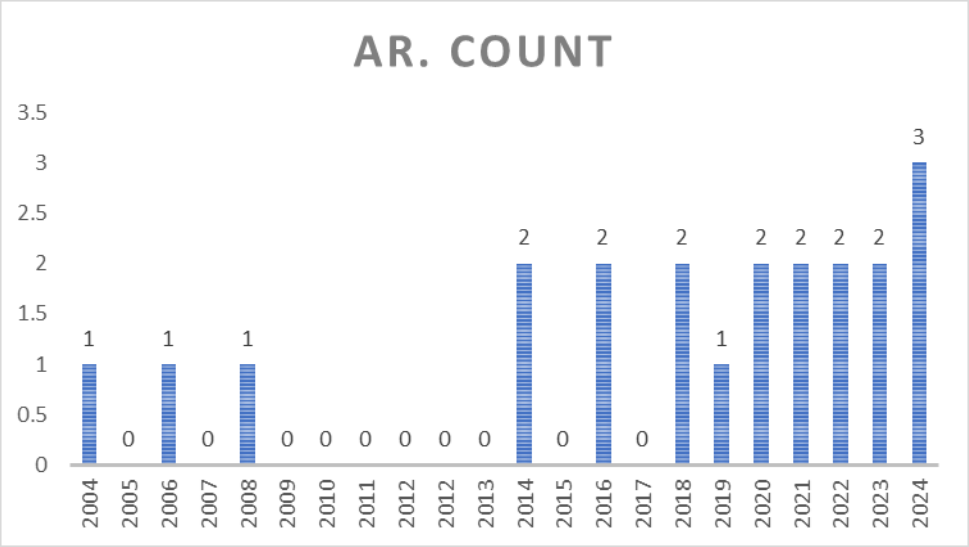

Figure 1: The chart illustrates the number of related studies published annually between 2004 and 2024.

Content Analysis:

Table 5: Studies have mentioned the identification of Point Cloud technology

1-A method of point cloud stitching based on the mechanical arm and laser 2-A point cloud simplification algorithm for mechanical part inspection 3-Leaf Model Reconstruction and Mechanical Deformation Based on Laser Point Cloud 4-Point cloud boundary detection in preprocessor of optical-	Recognizing Point Cloud Technology

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mechanical integrated simulation 5-Predicting the Mechanical Behavior of Additively Manufactured Mechanical Metamaterials Using Point Cloud Representation Learning 6-Reconstruction of consistent 3D CAD models from point cloud data using a priori CAD models 7-Three-dimensional point cloud analysis for automatic inspection of complex aeronautical mechanical assemblies	

The table includes titles of various studies related to Point Cloud technology and its applications in the mechanical field.

Table 6: Studies that have highlighted the importance and benefits of using Point Cloud technology.

1-3D point cloud analysis for automatic inspection of aeronautical mechanical assemblies 2-Point cloud and visual feature-based tracking method for an augmented reality-aided mechanical assembly system 3-From a 3D point cloud to an engineering CAD model: A knowledge-product- based approach for reverse engineering 4-Generalized Grasping for Mechanical Grippers for Unknown Objects with Partial Point Cloud Representations 5-Laser scanning and point cloud segmentation for contactless geo-mechanical surveying 6-Leaf Model Reconstruction and Mechanical Deformation Based on Laser Point Cloud 7-Predicting the Mechanical Behavior of Additively Manufactured Mechanical Metamaterials Using Point Cloud Representation Learning 8-Reconstruction of consistent 3D CAD models from point cloud data using a priori CAD models 9-Three-dimensional point cloud analysis for automatic inspection of complex aeronautical mechanical assemblies	Explaining the importance and benefits of using Point Cloud technology.

The table includes studies investigating the use of Point Cloud technology in mechanical engineering, such as three-dimensional point cloud analysis for inspecting aeronautical assemblies and reconstructing CAD models from point cloud data, contributing to improving accuracy and efficiency in industrial processes.

Table7: Enhancing the effectiveness of surveying methods used in creating three-dimensional models

1-Point cloud and visual feature-based tracking method for an augmented reality-aided mechanical assembly system 2-Laser scanning and point cloud segmentation for contactless geo-mechanical surveying 3-Reconstruction of consistent 3D CAD models from point cloud data using a priori CAD models	Enhancing the effectiveness of surveying methods used in creating three-dimensional models of existing buildings

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Table 8: Utilizing point clouds in the maintenance of mechanical systems

1-Apoint cloud simplification algorithm for mechanical part inspection 2-Point cloud and visual feature-based tracking method for an augmented reality-aided mechanical assembly system	Utilizing point clouds for maintenance of mechanical systems

4. Discussion

Based on the results presented in the study, it is evident that point cloud technology plays a vital role in enhancing the performance[12, 13] and efficiency of mechanical assembly systems and automatic inspection of mechanical assemblies [14, 15], through its applications in augmented reality-based tracking and three-dimensional point cloud analysis [16, 17, 18]. The studies also demonstrated tangible results in simplifying the processes of inspecting mechanical parts and predicting the behavior of manufactured mechanical systems using additive materials through point cloud representation learning. These findings underscore the importance of utilizing this technology in system maintenance and improving industrial processes overall [19]. Consequently, point cloud technology can play a pivotal role in enhancing the efficiency and accuracy of design and production in industries relying on mechanical systems, highlighting the significance of ongoing research and development in this field to achieve sustainable and tangible progress.

5. Conclusions

Summary of Key Findings:

The study demonstrates that point cloud technology plays a crucial role in enhancing the performance and efficiency of mechanical assembly systems and automatic inspection of mechanical assemblies, through its applications in augmented reality-based tracking and three-dimensional point cloud analysis. Prominent researchers in this field are highlighted in the cited studies, underscoring the significance of this technology and its contributions to advancing industrial processes and maintaining mechanical systems. On the other hand, the table focusing on the most cited research indicates a predominant focus on point cloud technology for analyzing complex mechanical systems and performing automatic inspections, reflecting substantial interest in advanced industrial applications and innovation in this field. These results illustrate that point cloud technology significantly enhances the efficiency and accuracy of design and production in industries reliant on mechanical systems, emphasizing the importance of continuous research and development to achieve sustainable and tangible progress.

Concluding Remarks:

Based on the results and analysis presented in the research, several important recommendations can be made to enhance the understanding and application of point cloud technology in the mechanical context. It is recommended to increase investment in research and development to develop new tools and techniques for analyzing and utilizing point cloud technology in manufacturing and mechanical system maintenance. This can contribute to improving the accuracy and efficiency of design and production. Furthermore, enhancing educational and training programs for engineers and technicians in the use of point cloud technologies is essential. This will help in equipping them with the necessary skills to effectively and accurately analyze three-dimensional data. Promoting existing industrial applications and encouraging collaboration between countries and industrial institutions to exchange knowledge and technologies regarding the use of point cloud technology are also crucial steps. This enables keeping pace with the latest developments and innovations in this field. Governments and companies should also support digital infrastructures that facilitate the storage and processing of large volumes of three-dimensional data. This contributes to developing more advanced applications for point cloud technology.

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References

[1] Kadi, A.J., et al., *A Pilot Study on the Indirect Effect of Syrian Construction Firms' Innovation Orientation on the Tourism Industry*, in *Handbook of Technology Application in Tourism in Asia*. 2022, Springer. p. 645-667.

[2] Bryde, D., M. Broquetas, and J.M. Volm, *The project benefits of building information modelling (BIM).* International journal of project management, 2013. **31**(7): p. 971-980.

[3] Fabio, R., *From point cloud to surface: the modeling and visualization problem.* International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 2003. **34**(5): p. W10.

[4] Kim, S., S. Kim, and D.-E. Lee, *Sustainable application of hybrid point cloud and BIM method for tracking construction progress.* Sustainability, 2020. **12**(10): p. 4106.

[5] 1Suermann, P.C., *Evaluating the impact of building information modeling (BIM) on construction*. 2009: University of Florida.

[6] Kadid, A., et al., *Bibliometric Study of E-Government in Kuwait.*

[7] Abrabba, S.A., et al., *A Biblio-Systematic Analysis of Factors Affecting the Compliance of Residential Planning Standards and Regulations: A Conceptual Framework.* Civil Engineering and Architecture, 2021. **9**(3): p. 646-655.

[8] KADI, A.J., *Biblio-Systematic Review of the Factors Affecting Selection of Religious Translation Strategies.*

[9] Amrouni, K. and R.A. Arshah. *A bibliometric analysis of the E-government studies with (UTAUT)*. in *Proceedings of the FGIC 2nd Conference on Governance and Integrity, Kuantan, Malaysia*. 2019.

[10] Barberi, E., et al., *Differential entropy-based analysis of point clouds: novel applications and methods.* 2023.

[11] Elhendawi, A.I.N., *Methodology for BIM Implementation in KSA in AEC Industry.* Master of Science MSc in Construction Project Management), Edinburgh Napier University, UK, 2018.

[12] Xu, Y. and U. Stilla, *Toward building and civil infrastructure reconstruction from point clouds: A review on data and key techniques.* IEEE journal of selected topics in applied earth observations and remote sensing, 2021. **14**: p. 2857-2885.

[13] Wang, J., et al., *Research trend of the unified theory of acceptance and use of technology theory: A bibliometric analysis.* Sustainability, 2021. **14**(1): p. 10.

[14] Mendoza, H.A., *Sustainable practices and challenges of farm destinations.* International Journal of Academe and Industry Research, 2022. **3**(2): p. 1-22.

[15] Cenka, B.A.N. and Z.A. Hasibuan. *Enhancing educational services using cloud technology*. in *2013 International Conference of Information and Communication Technology (ICoICT)*. 2013. IEEE.

[16] Kadi, A.J., et al., *The Effect of Innovation Barriers on Construction Firms' Innovation Orientation.* European Proceedings of Social and Behavioural Sciences.

[17] Saleh, F., Elhendawi, A., Darwish, A.S. and Farrell, P., 2024. A Framework for Leveraging the Incorporation of AI, BIM, and IoT to Achieve Smart Sustainable Cities. *Journal of Intelligent Systems and Internet of Things*, *11*(2), pp.75-84.

[18] Saleh, F., Elhendawi, A., Darwish, A.S. and Farrell, P., 2024. An ICT-based Framework for Innovative Integration between BIM and Lean Practices Obtaining Smart Sustainable Cities. *Fusion: Practice and Applications (FPA)*, *68*.

Doi: https://doi.org/10.54216/IJBES.100202
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[19] Elgendi, A.F., Elhendawi, A., Youssef, W.M.M. and Darwish, A.S., 2021. The Vulnerability of the Construction Ergonomics to Covid-19 and Its Probability Impact in Combating the Virus. *International Journal*, *4*(1), pp.01-19.

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