Integrating Clinical Engineering into Hospital Design: A Multidisciplinary Approach to Optimizing Healthcare Infrastructure

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ABSTRACT

Objectives: To analyze the challenges and limitations in hospital infrastructure development within Peru's health system, focusing on the role of clinical engineers, technological asset management, and Building Information Modeling (BIM) technology in optimizing healthcare delivery. This study aims to propose a multidisciplinary framework for improving hospital design, construction, operation, and maintenance.

Methods: A descriptive and analytical approach was used to evaluate the current state of hospital infrastructure in Peru. Key information was gathered from government reports, technical guidelines, and international standards related to healthcare facility design and management. The study also incorporated insights from multidisciplinary collaboration, emphasizing the involvement of clinical engineers in each stage of hospital development, including conceptualization, design, construction, and operation. The importance of technological asset and risk management frameworks, as well as the application of BIM, was examined to identify best practices and solutions.

Conclusions: The study concludes that Peru's health sector faces significant challenges in hospital infrastructure development, including inefficient planning, insufficient coordination, and outdated methodologies. The inclusion of clinical engineers as key stakeholders in the design and operational processes can enhance the alignment of infrastructure with clinical and technological needs. The integration of BIM technology provides a powerful tool for improving design accuracy, operational efficiency, and lifecycle management of healthcare facilities. A multidisciplinary approach, involving architects, clinical engineers, and regulatory authorities, is critical for addressing these challenges and ensuring sustainable, patient-centered hospital designs.

Keywords -Hospital Infrastructure, Clinical Engineering, Building Information Modeling (BIM), Healthcare Technology Management, Technological Risk Management, Preventive Maintenance, Peru Health System, Multidisciplinary Collaboration.

INTRODUCTION

In Peru, the health system is divided into two subsystems, public and private, and the governing body is the Ministry of Health.[1,2] There are more than 7,000 health facilities, 70% of which are health posts.[3]

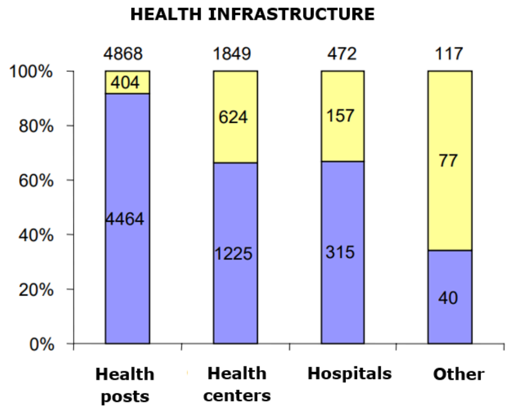

FIGURE 1. Types of health infrastructure. (Adapted from Analysis of the Health Sector of Peru[3])

Of the total number of hospitals, 66.73% are located in the interior of the country, and 25 regional governments were formed as part of the decentralization process. Each regional government organized its Regional Health Directorate (Diresa)[4] to manage services, as well as the hospital infrastructure needed according to the demographic population to be served.

According to the "Diagnóstico de brechas de infraestructura o acceso a servicios del sector salud", the health sector in Peru faces multiple limitations that make it difficult to close gaps in infrastructure and services.[5] Among the challenges highlighted are the deficiencies in the terms of reference and methodologies used in pre-investment studies, which generate problems in the designs and technical files, often resulting in delays and cost overruns. These limitations lead to work stoppages, legal conflicts and even arbitration, hindering the completion of essential projects for the improvement of the health system.[5]

HOSPITALS AT RISK

Hospital	Regional Government	Investment	Progress	Years under construction	State of the work
Hospital María Auxiliadora	Amazonas	S/113,979,137	28%	4	Unfinished
Hospital Subregional de Andahuaylas	Apurímac	S/160,142,696	54%	10	Unfinished
Hospital Challhuahuacho	Apurímac	S/85,246,573	75%	6	Suspended
Hospital Cotahuasi	Arequipa	S/73,766,927	63%	7	Suspended
Hospital de Espinar	Cusco	S/130,822,649	28%	6	Unfinished
Hospital Castrovirreyna	Huancavelica	S/61,571,005	4%	2	Unfinished
Hospital Regional Zacarías Correa Valdivia	Huancavelica	S/345,056,650	39%	5	Suspended
Hospital Tingo María	Huánuco	S/220,930,055	76%	12	Unfinished
Hospital de Apoyo Manuel Higa Arakaki	Junín	S/120,869,914	34%	7	Suspended
Hospital San Martín de Pangoa	Junín	S/111,003,967	50%	6	Unfinished

FIGURE 2. Hospital at risk (Adapted from the report of the Investment Bank of the Ministry of Economy and Finance, and Ministry of Health (2023)[6])

Figure 2 describes the case of 12 hospitals, most of which have been under construction for between 4 and 8 years, a range that suggests a lack of planning to meet the established deadlines. The Ministry of Health has 23 hospital works that have been under construction for an average of six years, the main causes are:

Hospital Design

The design of hospitals focuses on the areas of services [7] to be provided and the support, logistical or operational spaces, which are determined according to a previous study based on a medical program that will give the degree of complexity and category. The professions involved in the project are a multidisciplinary team with economists, doctors and others (mainly from the MEF and MINSA). The planning criteria are based on population, demographic and geographic figures and data, and their subsequent translation into the portfolio of services.

In the context of hospital project regulations, the guidelines established since 1978 [8] provide a robust framework to ensure the quality, safety, and functionality of healthcare facilities. These guidelines are built upon seven foundational pillars, which address the legal, technical, and operational aspects required for hospital infrastructure.

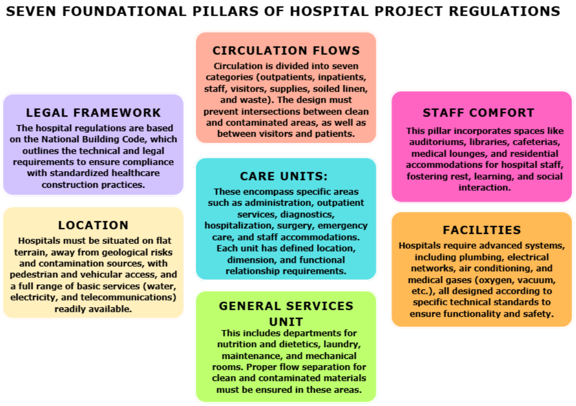

FIGURE 3. Seven foundational pillars of hospital project regulations[8]

The regulations lack specific criteria to account for geographical distinctions or the unique needs of hospitals based on their level of service autonomy. This omission creates challenges in adapting the standards to diverse regional contexts, potentially affecting the efficiency, accessibility, and functionality of healthcare infrastructure in areas with distinct environmental, demographic, or resource-related characteristics.

The construction of hospitals involves a series of critical stages that must be carefully managed to ensure the successful delivery of functional, safe, and efficient healthcare facilities. According to CIIES and CIP[9], there are four main phases in this process: conceptualization and analysis, design and detailed engineering, construction, and project handover and operation. Each stage presents its own set of challenges, which, if not addressed, can lead to inefficiencies, increased costs, and compromised healthcare delivery.

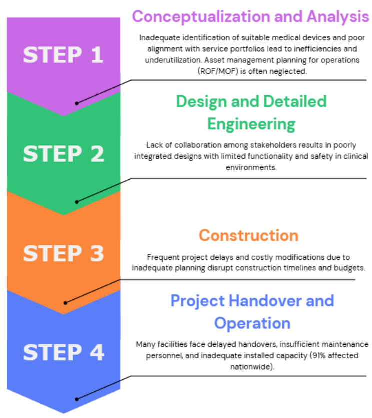

FIGURE 3. Steps for hospital design[9]

Operation and maintenance

Operation and maintenance in hospital facilities are essential components to ensure proper and efficient operation over time. This process goes beyond simple regulatory compliance for the installation of medical equipment. A comprehensive plan should include continuous training of technical staff, allowing efficient use of devices and reducing the likelihood of operational failures.[10] Preventive maintenance is an essential strategy to minimize downtime, reduce unexpected repair costs and extend the useful life of medical equipment.[11] The importance of proper management of the flow of people, supplies and services within the hospital, since optimizing these aspects not only improves care times, but also reduces stress on patients and facilitates the tasks of health personnel. These practices form a solid foundation to ensure that medical facilities operate effectively.[12]

Infrastructure and equipment management

A comprehensive approach is essential to address the dynamic needs of the health sector. According to the World Health Organization,[13] the procurement and planning of medical equipment should be based on a thorough analysis of the hospital's needs, taking into account factors such as the epidemiological profile and staff capabilities. It is important to implement continuous monitoring systems to identify failures and opportunities for improvement, which is essential to avoid cost overruns and maximize operational efficiency.[14] It is important to keep technological equipment constantly updated, since advances in medical tools can significantly influence the quality of diagnoses and treatments offered.[15]

Analyzing the causes, we conclude that the problem is that the hospitals are not operational or functioning, neither operation nor maintenance has been considered, there are hospitals that are 100% built but do not have a management system. To overcome these problems, it is essential to strengthen coordination and organization among the responsible entities and ensure clear processes in investment management. In addition, it is crucial to improve the functional articulation between the different units in charge of formulating and executing projects. The persistence of these difficulties highlights the urgent need to implement a comprehensive and efficient management system. This system should prioritize personnel training, standardization of procedures and transparency in the use of resources, thus ensuring that health investments respond effectively to the priority needs of the population.

TEAM THAT DESIGNS THE HOSPITALS

Hospital design is a multidisciplinary task, but historically it has been led by architects. While these professionals have the technical skills to conceptualize spaces according to data and regulations provided, they generally lack specific training in clinical practice and the functional use of these environments. This limits their ability to adapt designs to the actual needs of patients and healthcare staff. Collaboration between architects and clinical experts is essential to ensure that hospitals not only meet technical standards, but are also functional and fit for purpose.[16] There is a significant shortage of architects specialized in the design, management and development of hospital projects that integrate all the necessary features. This deficit compromises the ability of health systems to have optimal facilities. Specialization in hospital architecture is crucial to address the complexity inherent in these projects and to ensure adequate planning that considers both technical and human aspects.[17]

Another important profile is that of institutional reviewers in charge of evaluating projects. However, their approach is often restricted to compliance with standardized regulations, without considering the situational particularities of each setting. According to the World Health Organization, the lack of flexibility in the application of standards can limit the adaptability of hospital designs to the specific needs of the communities they are meant to serve.[18]

Finally, fitters play a crucial role in hospital design, as they are responsible for determining how spaces will be occupied, their functions, dimensions, and the types of connections required for medical equipment. Many spaces in a hospital are purely functional and are designed exclusively to house specialized equipment. This underscores the importance of proper integration between the architectural design and the technical specifications of the medical equipment to ensure the efficiency and functionality of the spaces.[19]

SOLUTION PROPOSAL

Role of the Clinical Engineer in hospital design

The challenge is significant, since it requires that profiles such as architects, reviewers and equippers have a comprehensive knowledge of both systemic aspects and clinical practice. For this reason, the presence of clinical engineers in healthcare systems is essential. According to the International Federation of Medical and Biological Engineering (IFMBE) and the American College of Clinical Engineering (ACCE), the clinical engineer is defined as a "professional qualified by academic training and/or certification to practice engineering in the health care environment, where technology related to health services is created, implemented, taught, regulated, managed or maintained".[20,21]

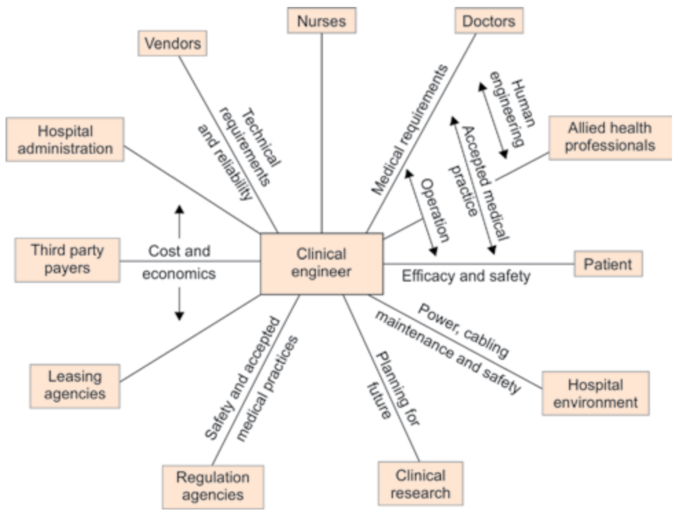

FIGURE 4. Diagram illustrating the range of interactions in which a clinical engineer might be required to engage in a hospital setting[22]

According to Fig. 4 the clinical engineer within the healthcare system, highlighting his or her interaction with multiple stakeholders and key areas. This professional acts as an essential link between technical, medical, regulatory and economic aspects, ensuring the safety, efficacy and sustainability of healthcare technology. His work involves collaborating with physicians, nurses and other healthcare professionals to meet medical requirements through human engineering and accepted practices. In addition, he or she is directly involved in the safety and efficacy of devices used in patient care, while contributing to the maintenance of the technology infrastructure and planning for future needs in the hospital environment. Likewise, the clinical engineer plays a crucial role in the evaluation of costs and benefits together with hospital administration, leasing agencies and third-party payers, promoting economic sustainability. He also interacts with suppliers and regulatory bodies to ensure compliance with technical and regulatory standards. Finally, its involvement in clinical research fosters the integration of new technologies and medical practices. This scenario reinforces the importance of including clinical engineers in multidisciplinary teams, as mentioned above, to comprehensively address technical and clinical challenges within healthcare systems.[22]

As mentioned above, according to CIIES and CIP9, the four key stages identified in hospital design set out the specific roles that the clinical engineer would play in each stage[9]:

Stage 1: Design and analysis

In this initial phase, the clinical engineer plays a key role in ensuring that technology and infrastructure solutions are aligned with clinical and functional needs.

- Contribution to the Medical-Functional Analysis, identifies the clinical and operational needs of the hospital environment, considering technical and functional aspects for the design and selection of technologies.
- Evaluation of Technologies Applied to Medical Devices,carrying out comparative studies of medical devices (MD) to evaluate their efficacy, safety and cost-benefit ratio.
- Modelling and simulation of the clinical environment and medical devices, use modelling tools to predict the performance of devices under real conditions.
- Initial Medical Device Requirements, define technical and functional specifications to ensure that MDs meet clinical standards.
- Facility and Medical Device Engineering Requirements, determine the number and profile of engineers required for the operation and maintenance of MDs.
- BIM Modelling of Clinical Services, incorporate building information modelling (BIM) to plan and simulate the layout of clinical spaces and their interaction with technology.

Stage 2: Design and Detailed Engineering

This stage focuses on ensuring that the technical design meets clinical and regulatory requirements.

- Compatibility with Clinical Practice Guidelines (CPGs),verify that the designed technologies are compatible with clinical best practices.
- Compliance with Standards, Codes and Regulations in the Clinical Environment and Medical Devices, ensuring that the design complies with standards such as IEC 60601 for medical device safety.
- Oversight of Clinical Design Criteria, validate that the design addresses aspects such as ergonomics, safety and ease of use in the clinical environment.

Stage 3: Construction

During the construction phase, the clinical engineer oversees the implementation of clinical technologies and services.

- Medical Device Supply Chain Management, coordinate the procurement, transportation and installation of medical devices.
- Medical Device Commissioning, validate the installation and operation of MDs, ensuring that they meet technical and functional specifications.
- Medical Device Supplier Evaluation, conduct supplier analysis to ensure the quality and reliability of equipment.
- Verification of Standards, Codes and Regulations, ensuring that facilities and MDs comply with national and international regulations.
- Functionality and Safety Supervision of Clinical Services, ensure that technological services and infrastructure meet quality and safety criteria.

Stage 4: Handover and Operation

In this final stage, the clinical engineer is responsible for the operational management and maintenance of healthcare technologies.

- Inventory Generation from Hospital BIM Design, create and maintain an updated inventory based on BIM models.
- Healthcare Technology Management (HTM), oversee the entire lifecycle of medical devices, from installation to decommissioning.
- Reliability-Centered Maintenance (RCM), implement reliability-based maintenance strategies to maximize equipment uptime.
- Risk-Based Maintenance, prioritize maintenance based on the risks associated with the failure of medical devices.
- Scheduled Medical Device Inspections, perform periodic inspections to ensure continuous compliance with norms and standards.
- Preventive and Predictive Maintenance of Medical Devices, prevent failures through regular maintenance programs and predictive techniques, such as data analysis.
- Biomedical Metrology, calibrate and verify medical devices to ensure measurement accuracy.

Hospital Infrastructure

The use of Building Information Modeling (BIM) technology is essential for developing a comprehensive design library for hospital infrastructure. BIM provides a collaborative platform where multidisciplinary teams, including clinical engineers, can integrate their expertise into the design, construction, and operation phases of healthcare facilities. This approach enables the creation of detailed 3D models that incorporate not only architectural elements but also mechanical, electrical, and plumbing (MEP) systems, medical equipment placement, and clinical workflow optimization. Establishing these directives at the state level is crucial to ensure uniformity and flexibility in hospital infrastructure planning, while accommodating the diverse geographies and healthcare needs of the country.[23]

Clinical engineers play a pivotal role in the application of BIM technology within hospital settings. Their involvement begins with the integration of medical equipment into BIM models, ensuring accurate representation of spatial requirements, connectivity, and compatibility with other systems. This precise planning reduces errors during installation and streamlines construction processes. Furthermore, BIM enables clinical engineers to simulate clinical workflows and assess the functionality of medical equipment within the designed space, optimizing processes and ensuring the facility aligns with healthcare delivery needs. This level of simulation and analysis is critical in creating patient-centered environments that meet the highest standards of care.[24]

Another key contribution of clinical engineers is their ability to use BIM for the lifecycle management of medical devices. From procurement to maintenance and eventual decommissioning, BIM provides an efficient way to track and manage medical equipment, improving the effectiveness of Healthcare Technology Management (HTM) systems. Additionally, clinical engineers ensure compliance with healthcare-specific regulations and standards, such as IEC 60601 for medical electrical equipment, by embedding these requirements into the BIM models from the early design stages. This proactive approach minimizes non-compliance risks and ensures that hospital infrastructure adheres to both national and international standards.[25]

The collaborative nature of BIM further enhances its utility in hospital projects. Clinical engineers work closely with architects, construction managers, and hospital administrators to ensure that infrastructure design meets clinical requirements and operational goals. This interdisciplinary collaboration fosters better communication and alignment of priorities, resulting in facilities that are not only functional but also adaptable to future advancements in healthcare technology.[26]

BIM technology offers numerous advantages for hospital infrastructure development. It enhances precision and accuracy by minimizing design errors and reducing rework during construction. The shared BIM model acts as a single source of truth, improving communication between stakeholders and fostering efficient decision-making. Additionally, BIM enables better cost and time management by optimizing planning and coordination. Its adaptability allows for tailoring designs to local geographical and cultural requirements, ensuring that healthcare facilities are contextually relevant and sustainable.[27]

Operation and maintenance management

Operation management must comprehensively address the lifecycle of medical devices, encompassing all stages from acquisition, installation, operation, maintenance, and eventual decommissioning. It is essential to implement strategies that ensure maximum efficiency, safety, and availability of equipment, thereby guaranteeing the continuity of clinical services. Additionally, clear processes and specific protocols must be established to enable data-driven management, focusing on preventive, predictive, and reliability-centered maintenance.[28] This approach not only optimizes resources but also contributes to the sustainability of the healthcare system by extending the lifespan of medical devices and minimizing the risk of critical failures.

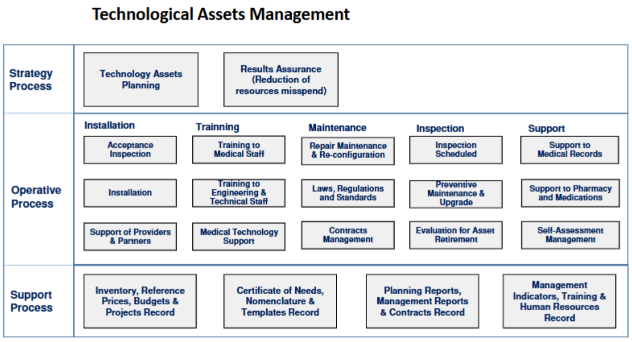

FIGURE 5. Technological Assets Management

Technological assets management in healthcare settings is divided into three main processes: strategy, operative, and support. Each process outlines specific activities aimed at ensuring the effective lifecycle management of medical technologies, from planning to maintenance and operation.[29]

The strategy process focuses on high-level planning and resource optimization. It includes technology assets planning, which involves defining the acquisition, deployment, and management of medical technologies, and results assurance, aimed at reducing the misallocation of resources and ensuring that investments align with organizational goals.

The operative process encompasses day-to-day activities related to installation, training, maintenance, inspection, and support. During installation, tasks such as acceptance inspections and collaboration with providers ensure that equipment meets quality standards. Training programs for both medical staff and technical teams are implemented to ensure proper use and maintenance of technologies. Maintenance involves repair, reconfiguration, compliance with laws and standards, and management of service contracts. Regular inspection schedules and preventive maintenance plans are critical to maintaining operational reliability, while asset retirement evaluations ensure that outdated equipment is phased out responsibly. The support aspect of this process includes assistance with medical records, pharmacy systems, and self-assessment tools to improve management practices.

The support process underpins the strategy and operative processes by providing the necessary tools and resources. This includes maintaining an accurate inventory, reference prices, budgets, and project records, as well as managing certificates of needs and templates to standardize processes. Additionally, the support process involves creating planning and management reports, ensuring contract compliance, and tracking management indicators, staff training, and human resource records to foster continuous improvement.

This comprehensive framework ensures that healthcare organizations can manage their technological assets efficiently, aligning operational needs with strategic goals while maintaining compliance and optimizing resources.

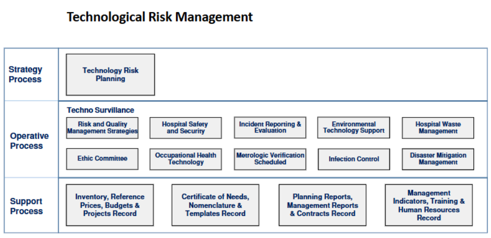

FIGURE 6. Technological Risk Management

Technological risk management in healthcare provides a structured approach to identifying, mitigating, and monitoring risks associated with medical technologies. This model is divided into three main processes: strategy, operative, and support, each contributing to a safer and more reliable healthcare environment.[30]

The strategy process focuses on technology risk planning, which involves the identification and assessment of potential risks related to healthcare technologies. This step ensures that risk management strategies align with the organization's operational goals and comply with regulatory requirements.

The operative process includes techno-surveillance activities aimed at monitoring and addressing risks in real time. Risk and quality management strategies are implemented to oversee safety and operational standards. Hospital safety and security protocols ensure that technologies contribute to a safe environment, while incident reporting and evaluation mechanisms facilitate learning from adverse events. The process also covers environmental technology support, focusing on reducing the environmental impact of healthcare technologies, and hospital waste management, addressing the proper disposal of hazardous and non-hazardous materials.

In addition, the operative process incorporates health technology monitoring, such as ethics committee oversight, to ensure compliance with ethical principles, and occupational health technology to manage risks to healthcare workers. Metrologic verification schedules ensure regular calibration and reliability of medical devices, while infection control measures help prevent healthcare-associated infections. Finally, disaster mitigation management involves planning and preparedness to reduce the impact of natural or technological disasters on healthcare services.

The support process provides the foundational resources and documentation for effective risk management. This includes maintaining inventory records, budgets, and project documentation, as well as certificates of needs and templates to standardize workflows. It also involves generating planning and management reports to track progress and manage contracts. Management indicators, staff training, and human resource records ensure that the organization remains equipped to handle technological risks effectively.

By integrating strategy, operational execution, and support, this framework enables healthcare facilities to manage technological risks comprehensively. It ensures compliance with regulations, minimizes potential hazards, and fosters a culture of safety and reliability in healthcare delivery.

Expected Results and Discussion

The implementation of a multidisciplinary approach involving clinical engineers, supported by Building Information Modeling (BIM) technology, is expected to significantly enhance hospital infrastructure in Peru. By integrating clinical needs with technological and architectural planning, healthcare facilities can achieve improved operational efficiency, reduced construction delays, and better alignment with patient care requirements. The adoption of preventive and predictive maintenance strategies, alongside proper lifecycle management of medical devices, will ensure the sustainability and reliability of healthcare technology. However, successful implementation requires clear regulatory frameworks, government investment, and comprehensive training for all stakeholders. This approach could be gradually introduced in pilot hospitals to refine processes and demonstrate its feasibility before scaling up across the healthcare system.

REFERENCES

1. *Decreto Legislativo que aprueba la Ley de Organización y Funciones del Ministerio de Salud*. (n.d.). Ministerio de Salud - MINSA. Retrieved January 17, 2025, from https://www.minsa.gob.pe/Recursos/OGTI/SINADEF/DL-1161.pdf
2. *Sistema de salud de Perú*. (n.d.). SciELO México. Retrieved January 17, 2025, from https://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0036-36342011000800019
3. Superintendencia de Entidades Prestadoras de Salud. (2001). *ANALISIS DEL SECTOR SALUD*. https://bvs.minsa.gob.pe/local/minsa/3159.pdf
4. Dirección Regional de Salud - Lima. (2008). *Organización*. https://www.gob.pe/institucion/regionlima-diresa/organizacion
5. Secretraia General del Ministerio de Salud. (2023, August). *DIAGNÓSTICO DE BRECHAS DE INFRAESTRUCTURA O ACCESO A SERVICIOS DEL SECTOR SALUD*. https://cdn.www.gob.pe/uploads/document/file/5

058113/Diagn%C3%B3stico%20de%20la%20Situaci%C3%B3n%20de%20%20Brechas%20de%20infraestructura%20o%20de%20acceso%20a%20servicios%20del%20Sector%20Salud%20%282025-2027%29.pdf
6. "Los 23 hospitales que están tardando seis años en construirse en Perú". Salud con lupa. https://saludconlupa.com/noticias/los-23-hospitales-que-estan-tardando-seis-anos-en-construirse-en-peru/
7. Untitled. (n.d.). Ministerio de Salud - MINSA. Retrieved January 17, 2025, from https://www.minsa.gob.pe/Recursos/OTRANS/08Proyectos/2021/PIM-SS-2021_norma-13.pdf
8. Direccion General de Salud de las Personas. (1996). *Norma técnica para proyectos de arquitectura hospitalaria*. https://www.gob.pe/institucion/minsa/informes-publicaciones/353242-normas-tecnicas-para-proyectos-de-arquitectura-hospitalaria
9. CIIES-CIP-CDL. (2023). *2da Conferencia CIIES-CIP-CDL: Proyectos de Infraestructura y Equipamiento de Establecimientos de Salud*. https://cdlima.org.pe/2da-conferencia-ciies-cip-cdl-proyectos-de-infraestructura-y-equipamiento-de-establecimientos-de-salud/
10. Mayra, M. N. (2024). *Biomedical equipment: preventive maintenance and its impact on performance*. https://doi.org/10.56183/iberotecs.v4i1.633
11. Downtime Reduction on Medical Equipment Maintenance at The Directorate of Biomedical Engineering in the Jordanian MOH. (2017). http://dx.doi.org/10.3991/ijoe.v13i02.6422
12. Ulrich, R. S. (n.d.). *The Role of the Physical Environment in the Hospital of the 21st Century: A Once-in-a-Lifetime Opportunity*. The Center for Health Design. Retrieved January 17, 2025, from https://www.healthdesign.org/system/files/Ulrich_Role%20of%20Physical_2004.pdf
13. WHO Medical device technical series. (2011). *Medical equipment maintenance programme overview*. https://www.who.int/publications/i/item/9789241501538
14. Cham, S. (n.d.). *The Role of Design in Healthcare Innovation and Future Digital Health. In: Rivas, H., Boillat, T. (eds) Digital Health. Health Informatics. Springer, Cham.* https://doi.org/10.1007/978-3-031-17666-1_11
15. Goldstein, S. M., & Ward, P. T. (2018). Sustaining innovation in hospital technology management. Journal of Operations Management.
16. Chauhan, N., & Goyal, S. (2020). The Role of Collaborative Design in Healthcare Infrastructure. *Journal of Healthcare Design and Management.* https://doi.org/10.1111/j.0011-7315.2004.02570.x.
17. Hernández, R., López, A., & García, M. (2018). Specialized Architecture for Healthcare Facilities: Bridging the Gap Between Design and Practice. *International Journal of Hospital Infrastructure.*
18. World Health Organization (WHO). (2017). Framework for Planning and Designing Healthcare Facilities.
19. Almeida, R. T., & Costa, C. L. (2019). Infrastructure and Equipment Management in Health Services: Challenges and Solutions. *International Journal of Health Management.*
20. *"Clinical Engineering Definitions | CED IFMBE". CED IFMBE | Clinical Engineering Division. https://ced.ifmbe.org/resources/clinical-engineering-definitions/*
21. *"ClinicalEngineer"https://accenet.org/about/Pages/ClinicalEngineer.aspx*
22. *M. M. Singh, S. K. Patnaik, P. Srivastva, H. K. Satia y M. Singh, "Planning and Designing of Clinical Engineering Department in a Hospital", Int. J. Res. Found. Hospital Healthcare Admin., vol. 3, n.º 2, pp. 129–134, 2015. https://doi.org/10.5005/jp-journals-10035-1049*
23. *Zhang, G., y Sun, J. (2024). Investigación sobre diseño modular de espacios en hospitales de urgencias basado en innovación tecnológica BIM. Buildings . https://doi.org/10.3390/buildings14103237 .*
24. *Oakes, J., y Johns, R. (1973). El papel de la ingeniería clínica en la prestación de servicios de salud. IEEE Transactions on Biomedical Engineering , 3, 225-227. https://doi.org/10.1109/TBME.1973.324278 .*
25. *Alnaggar, A., y Papadonikolaki, E. (2019). Un modelo propuesto para la transformación digital de la gestión de requisitos en el diseño de instalaciones sanitarias..*
26. *Merschbrock, C., Hosseini, M., Martek, I., Arashpour, M. y Mignone, G. (2018). Rol colaborativo de los componentes sociotécnicos en redes de construcción basadas en BIM en dos hospitales. Journal of Management in Engineering . https://doi.org/10.1061/(ASCE)ME.1943-5479.0000605 .*
27. *Dmitrieva, T., Yashchenko, V. y Kuryshov, I. (2023). BIM como medio de diseño, construcción y operación de extremo a extremo. Izvestiya vuzov. Investitsii. Stroitelstvo. Nedvizhimost . https://doi.org/10.21285/2227-2917-2023-2-252-261 .*
28. *Sodhro, A., Pirbhulal, S. y Sangaiah, A. (2018). Convergencia de la IoT y la gestión del ciclo de vida del producto en la atención médica. Future Gener. Comput. Syst. , 86, 380-391. https://doi.org/10.1016/j.future.2018.03.052 .*
29. *McCarthy, J., Hegarty, F., Amoore, J., Blackett, P. y Scott, R. (2020). Gestión de activos de tecnología sanitaria., 17-30. https://doi.org/10.1016/b978-0-08-102694-6.00002-4 .*
30. *Mahmoud, T., Balachandran, W. y Altayyar, S. (2024). Promoción de la gestión sostenible de la tecnología sanitaria: desarrollo de un marco integral de evaluación de riesgos con un proceso de jerarquía analítica difusa, que integre factores externos e internos en la región del Golfo. Sustentabilidad . https://doi.org/10.3390/su16188197 .*