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ACOUSTIC QUALITY IN HEALTHCARE FACILITIES: AN INTEGRATED APPROACH FOR PATIENT WELL-BEING

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Abstract

This paper presents the findings from a Doctoral thesis in Architecture, investigating the impact of the sound environment on hospital patients' well-being. Representative inpatient wards were selected within four Italian hospitals to analyze acoustic criticalities, noise sources, and the subjective experience of users, using a mixed-methods approach. The results highlight that WHO limits are systematically exceeded. The complexity of the hospital environment needs an integrated approach that encompasses the various factors influencing the acoustic quality of the spaces. Finally, the research proposes a practical framework, consisting of a replicable investigation protocol and a checklist of design strategies to ensure acoustic quality control throughout every project phase.

Keywords: *acoustic comfort, healthcare facilities, evidence-based design, noise control, patient well-being*

1. Introduction

This contribution summarizes the results obtained during a Doctoral program in *Sustainability and Innovation for the design of the built environment and the product system* (curriculum in Architectural Technology) at the Department of Architecture (DiDA) of the University of Florence, Italy [1].

2. Acoustic well-being in the hospital setting

Well-being can be defined as the optimal balance between the biological, psychological, and social aspects that characterize an individual. In this view, health is understood as a state of complete physical, mental, and social well-being, rather than merely the absence of disease or infirmity [2].

Research has shown that the environment directly influences people's well-being. Specifically, the environmental quality in hospitals is a determining factor in patient recovery, as it directly affects the healing process and recovery times [3].

Florence Nightingale stated that "unnecessary noise is the cruellest absence of care which can be inflicted either on sick or well" [4].

The World Health Organization (WHO) identifies noise as a critical environmental factor, recommending an A-weighted equivalent sound pressure level (L_{Aeq}) below 30 dB(A) in patient areas during both day and night, with maximum levels (L_{AFmax}) always below 40 dB(A) [5].

Despite these established guidelines, current literature consistently reports sound levels that exceed recommended thresholds and continue to rise [6]. Furthermore, there is a lack of standardized protocols for evaluating the acoustic quality of hospital wards based on user-centered requirements [7]. Consequently, this research aimed to define a replicable investigative methodology and, subsequently, to develop evidence-based guidelines for the acoustic management of inpatient wards, intended for both healthcare administrators and designers. These findings provide an operational framework for future Italian national standards—which are currently lacking—specifically aimed at regulating acoustic comfort within healthcare environments.

3. Methods

Given the complexity of the hospital context, a mixed-method approach was adopted, combining quantitative and qualitative analyses for a comprehensive view of the phenomenon. First, a state-of-the-art study was conducted, analyzing national and international regulations and performing a systematic literature review using the PRISMA method [8].

The core of the investigation protocol consisted of field studies conducted in four Italian hospitals over three days per case study to validate the protocol.

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The fieldwork involved three types of investigations:

- Experimental acoustic measurements.
- Structured observations.
- In-depth interviews.

3.1 Selection criteria for case studies

Four major hospitals in the Tuscany region (Italy) were selected as case studies.

Within each facility, a representative inpatient ward was identified for analysis. Through consultation with hospital management, the selection was restricted to wards characterized by medium-to-high bed occupancy and low care intensity. These criteria ensured the exclusion of exceptionally quiet environments resulting from low occupancy, as well as highly critical contexts associated with severe patient conditions.

Regarding spatial configuration, the study focused exclusively on wards with triple- or quadruple-body layouts, characterized by a central corridor with patient rooms and service areas on both sides. Finally, the selection was narrowed to wards featuring two-bed rooms with en-suite toilets and a mirrored modular design, as these represent the most prevalent typologies in contemporary hospital architecture.

The specific architectural selection criteria applied across the four case studies and their ward plan layouts are illustrated in Figure 1 and Figure 2, respectively.

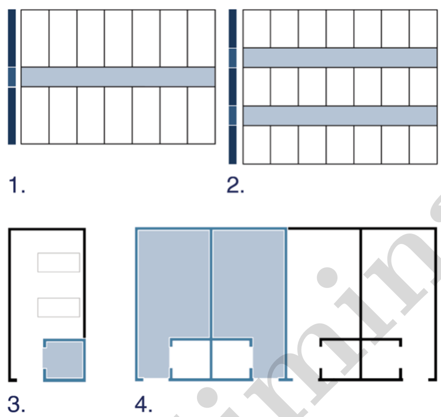

Figure 1. Case study selection criteria and ward layouts. Top, typical ward layout: 1) one-corridor ward layout, 2) two-corridor ward layout Bottom, room layout: 3) internal toilets located on the corridor side, 4) mirrored two-bed room.

3.2 Acoustic measurements

The acoustic characterization involved several investigative procedures:

- Short-term monitoring of sound pressure levels and frequency spectra within common areas during standard operational hours, aimed at quantifying the noise levels generated within the ward.
- Long-term monitoring (48-hour duration) of sound pressure levels and spectra in representative patient rooms, conducted under both occupied and unoccupied conditions, to evaluate the noise exposure reaching the patient.
- Room impulse response measurements and assessment of the standardized level difference ($D_{nT,w}$) between adjacent rooms and between rooms and corridors. These measurements were performed to determine the extent of noise transmission as a function of partition acoustic performance and flanking paths.

A representative setup of a monitored two-bed room under unoccupied conditions is depicted in Figure 3.

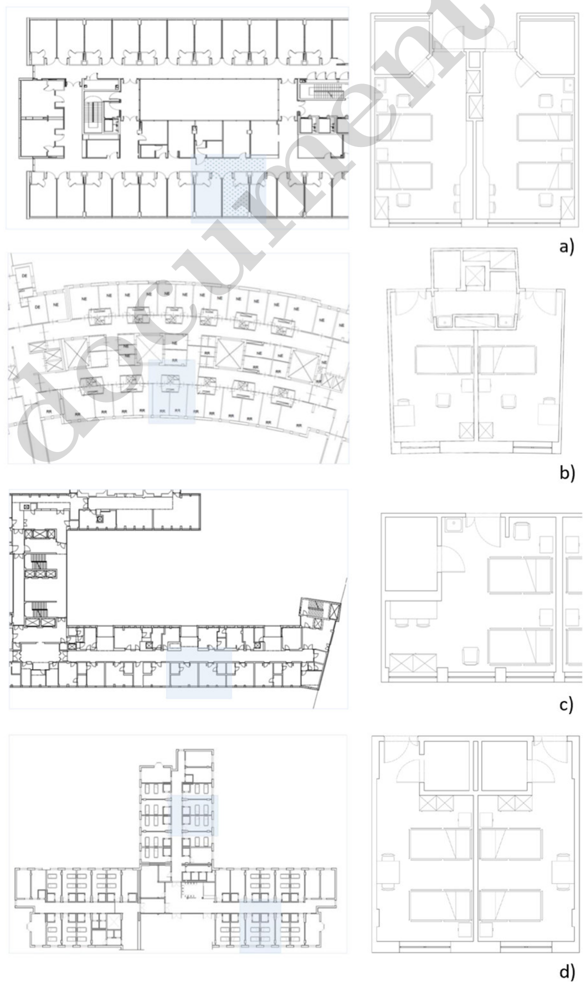

Figure 2. Floor plan layout of the typical patient rooms within the four case studies.

3.3 Structured observations

The structured observations took place within the corridors of the wards. Their purpose was to go beyond mere detection of sound pressure levels, by understanding the sounds of the ward, identifying the sources, their recurrence and location, while observing the habits of the users. Each observation had a minimum duration of 20 minutes at different times of the day, during the three days of overall investigations. Sound levels and spectra were monitored with a sound level meter during each observation period.

Figure 3. Typical two-bed room, monitored for 48 hours in unoccupied conditions with the door closed. The levels measured in this state are solely due to activities in adjacent rooms and transmitted through flanking paths.

3.4 In-depth interviews

In-depth interviews were conducted with healthcare staff to ensure that patients' recovery processes remained undisturbed. The primary objective of this qualitative analysis was to investigate sound perception and the subjective user experience through direct first-hand accounts. These semi-structured interviews addressed key thematic areas, including: environmental functionality, medical equipment, prevalent sound sources, spatial dynamics and usage habits, perceived barriers to acoustic comfort, and specific user needs and suggestions. The gathered text corpus was subsequently subjected to qualitative thematic analysis to extract recurrent semantic domains.

4. Results and discussion

This section presents a selection of findings derived from the in-field surveys. As shown in Figure 4, across all case studies, the sound pressure levels measured during both diurnal and nocturnal periods—under both occupied and unoccupied conditions—consistently exceeded the limits established by the WHO, with diurnal peak levels (L_{AFmax}) frequently approaching 85–90 dB(A) across the monitored wards.

Furthermore, standardized acoustic insulation measurements ($D_{nT,w}$), detailed in Figure 5, revealed poor partition performance across all analyzed configuration. Specifically, the standardized sound insulation ($D_{nT,w}$) between bedrooms and corridors stopped at 23–25 dB, falling significantly short of the 30 dB Italian mandatory threshold, mainly due to lightweight access doors lacking bottom seals. Similarly, the sound insulation between adjacent rooms was compromised by lateral transmission via the room-corridor-room path.

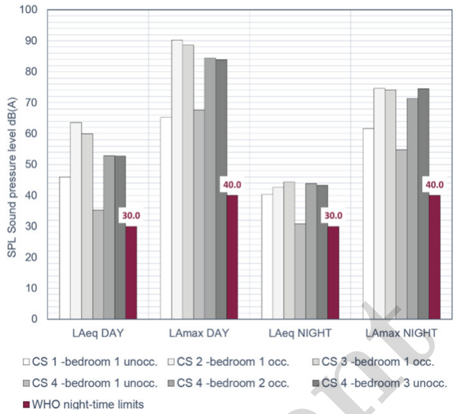

Figure 4. Results of the typical patient rooms monitored for 48 hours within four wards (under occupied conditions with the door open, "occ." in the graph, and unoccupied conditions with the door closed, "non-occ."). The graph shows the overall sound pressure levels in terms of L_{Aeq} and L_{AFmax} compared with the WHO limit values ("WHO night-time limits").

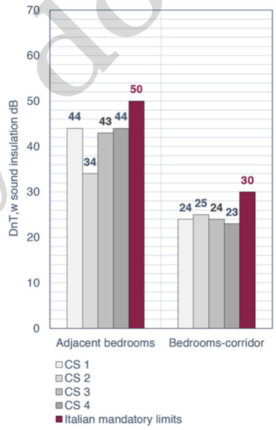

Figure 5. Measured sound insulation for the typical rooms across the four case studies: $D_{nT,w}$ for partitions between adjacent rooms and between rooms and corridors, compared with the mandatory limits in Italy.

Structured observations facilitated the identification and categorization of sound sources into seven primary groups:

- Mechanical and electrical systems (e.g., HVAC systems);
- Clinical devices (e.g., oxygen concentrators);
- Private electronic devices (e.g., mobile phones);
- Alarms (e.g., nurse call systems);
- Verbal communication;
- Anthropic activities (e.g., door slamming);

- Movement of furniture or equipment (e.g., trolleys and stretchers).

The recurrence of these sources varied by ward type. In the General Surgery ward, for instance, the majority of observed events were attributable to alarms, whereas in the Endocrine Surgery ward, verbal communication predominated.
This discrepancy relates to the varying levels of patient acuity: the former accommodates post-surgical patients with high dependency, while the latter involves elective surgeries where patients maintain greater autonomy.

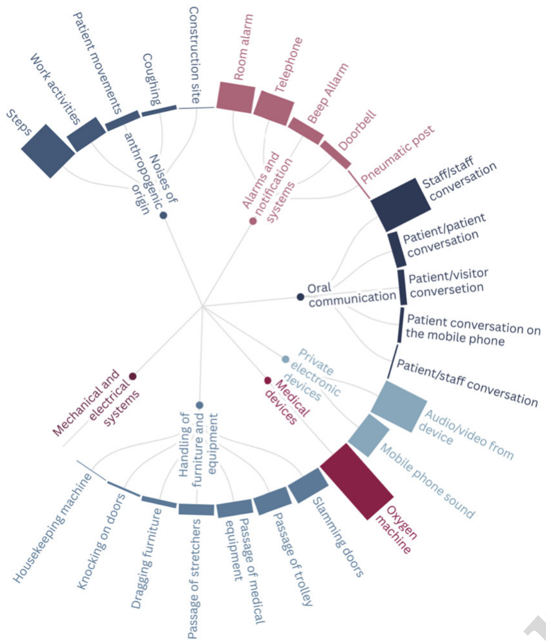

Figure 6. Distribution of sound source occurrences in a surgical ward (Tuscany, Italy). Different colours indicate sources grouped by category.

Through a qualitative thematic analysis of the interview transcriptions, recurring patterns were identified and user needs were classified into five primary semantic domains: tranquility and privacy, comfort, accessibility, patient safety, and acoustic isolation.
The qualitative data revealed a high level of awareness among healthcare staff regarding their own role in generating anthropic noise during daily operations.
To mitigate these criticalities, the interviewees proposed targeted architectural and operational intervention strategies. These include the implementation of customizable or pager-based alarm systems to minimize central desk noise, the installation of impact-dampening flooring in corridors to cushion trolley movement, and the creation of dedicated, soundproofed spaces for private telephone calls and emotional decompression. Furthermore, it was noted that although patient rooms comply with current dimensional standards, their restricted layouts necessitate the noisy displacement of furniture during bed transport, directly linking spatial configuration to acoustic quality degradation. These qualitative demands and user-suggested strategies directly informed the layout, organizational, and technical domains integrated into the design tool discussed in Figure 7.
The extensive investigations carried out yielded a vast dataset, of which this paper presents only selected highlights.
The data collected from the three investigations were analyzed using a methodological triangulation approach and benchmarked against existing literature. The resulting evidence informed the development of mitigation strategies, which were subsequently validated through consultations with technical stakeholders and healthcare management.
These intervention strategies are categorized into five primary areas, which form the conceptual backbone of the developed tool. As synthesized in Figure 7, the BiOs Check-List operationalizes these areas to facilitate coordination among stakeholders during the planning, design, and renovation phases of hospital wards:

- Internal organization of environments;
- Technical design solutions;
- Source-level sound emission control;
- User training and awareness;
- Acoustic accessibility.

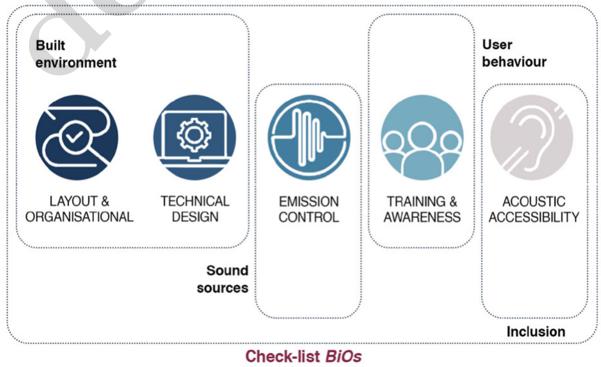

Figure 7. Schematic of the strategies for acoustic quality control in hospital wards, as outlined within the BiOs Check-List.

This tool is intended to facilitate coordination among stakeholders during the planning, design, and renovation phases of hospital wards.

5. Conclusions

Investing in acoustic quality represents more than a mere technical requirement; given the strong correlation between acoustics and patient clinical outcomes documented in the literature, it is a fundamental component of healthcare system efficiency. Although the investigations highlight the significant challenges in meeting WHO guidelines, the findings underscore the necessity for an integrated, tailor-made approach specifically designed for hospital environments. In this context, this research provides concrete operational tools—namely the investigation protocol and the design checklist—aimed at optimizing the design process and enhancing coordination among various stakeholders, with the ultimate goal of ensuring acoustic comfort within care spaces.

6. Future developments

The research focused on the acoustic well-being of patients within the wards and utilized interviews with healthcare staff primarily as a proxy to investigate patient acoustic well-being without disrupting their recovery processes. However, the direct impact of the acoustics on the healthcare staff's own occupational health remains unexplored, for whom acoustic comfort is determinant for clinical safety and the reduction of occupational stress. Furthermore, the strategies hypothesized for the wards should be extended to other scenarios of the complex hospital organism. Both these aspects are already being explored in depth within Specific Objective 4 (Hospital Environments) of the new BRIC INAIL 2024 ID07 project entitled "Extra-auditory effects of noise in school, university, and hospital environments and control of related injury risk," currently in progress.

7. Acknowledgments

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