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Technological innovation in the design process of an acoustic panel to the hospital environment

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Abstract. Acoustic pollution has become a global problem, but, having negative effects on the health and well-being of people, it becomes a variable to control in hospital environments. That is why this article presents the design of a panel with noise reduction properties and with characteristics that allow to replace the restrictions of the hospital environment, through the concepts of Home Warmth and Patient Safety as fundamental bases to limit the problem. The design exercise uses the VDI 2221 model and the problem / solution symmetry model in order to restrict the design and refine it without losing sight of the context for which the panel is designed. As a result, a design of the structure is obtained that later goes on to a stage of improvement of details, in which characteristics associated to the materials, production processes and other additional characteristics are defined.

1. Introduction

According to various studies, noise has a negative effect on the health and well-being of people, so the world health organization (WHO), cataloged it in 1972 as another form of pollution called acoustic pollution [1]. Although noise pollution can occur in all types of spaces, there is no doubt that the most vulnerable place to address this problem are the hospital environments, since they house a large number of people with health problems and whose recovery depends mostly of the conditions of calm of the environment where they are. Even though this is quite evident, the acoustic conditioning industry has provided few options for the acoustic treatment of spaces at the hospital level, due to the large number of requirements involved in fulfilling any clothing used in this type of environment. This is why this work was carried out in which a structured process of engineering design is carried out, specifically focused on covering the acoustic needs of the hospital environment, but with the differential of providing adequate cleaning conditions for these environments that must be met amount of regulations.

2. Methodology and results

The design process was carried out using the methodology proposed by the VDI 2221 model (Figure 1), which maintains a close relationship between the general problem and the secondary problems with their respective general and secondary solutions [2]. Next, will be presented the development of each stage of the VDI 2221 model around the described problem.



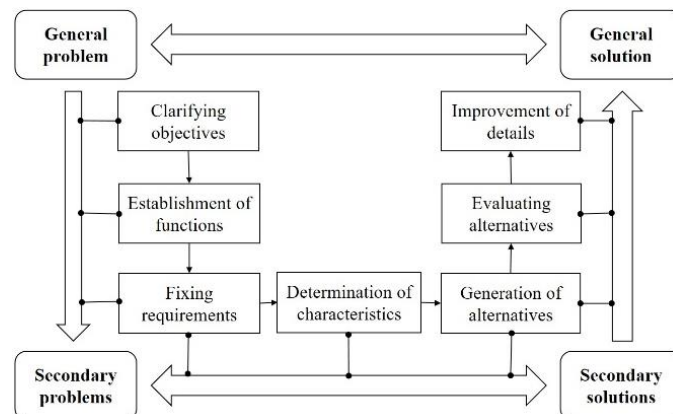


Figure 1. Model VDI 2221 of the design process in symmetric model of problem / solution.

2.1. Clarifying objectives

At this stage of design, it is important to take the problem and start with the analysis of how it can be addressed by setting goals. For this, it is use the method called "goals tree" in which the start point or input is the approach of the problem, for which, a contextualization was initially made with different types of sources (scientific articles, regulation of noise levels, regulation for hospitals, etc.) in order to make a better identification of the problem and structure a little the approach of the same.

Faced with this, different important circumstances were found to stand out; for example, the Ministry of the environment, housing and territorial development of Colombia limited the maximum noise levels recommended for quiet areas (which includes hospitals) by 55 dB during the day and 50 dB during the night [3]. This condition is hardly fulfilled at present for several reasons including in general, the noise levels of the main cities like Medellin are, in most areas, above 65 dB [4]. Another condition found in the contextualization of the problem refers to the important sources of noise in the hospital environment, such as biomedical equipment (monitors, ventilators, anesthesia machines, among others.), which can reach to emit sounds close to 78 dB [5]. Depending on the service and the operating conditions of the institution, these levels can harm the tranquility of the patients and, therefore, also their recovery process.

According to this, the problem was posed as "the need of a panel with noise reduction properties for separation of shared spaces in the hospital environment". With this, two important concepts are considered for a recovery process: the first is the concept of *Home Warmth*, which refers to the ability of a space to approach the domestic conditions in which the patient lives, so that you can have a more productive recovery process, just as if you were in your home [6]; and the second concept is *Patient Safety*, which seeks to minimize and, if possible, eliminate the risks for the patient associated with health care [7]. With all this, the goals tree presented in Figure 2 was raised, focused on the previously proposed problem and framed by the concepts of *Warmth of Home* and *Patient Safety*.

2.2. Establishment of the functions

Through this stage, is made a clear description of the main function that the panel will fulfill. Based on the concepts of *Home Warmth* and *Patient Safety*, plus the problem statement, it was determined that the main function of the panel is related to the noise reduction properties that it presents and the separation of spaces (represented by a black box in Figure 3). To understand this main function, it is important to know that when a wave hits a surface, 3 phenomena are generated: reflection, absorption and transmission [8]. This means that the energy of each sound wave is broken down into 3: a part of the energy is reflected by a reflected wave, another part is absorbed in the material and this, being absorbing, transforms it into heat; and finally, the rest of the energy cross the material by a transmitted wave [8]. This transmitted wave is the one received on the other side of the panel and presents a reduction of energy, which means a reduction of the perceived noise level. The Figure 4 develops this

whole concept of the operating principle of the panel, considering that in this case two contiguous spaces are separated but that they require a certain independence.

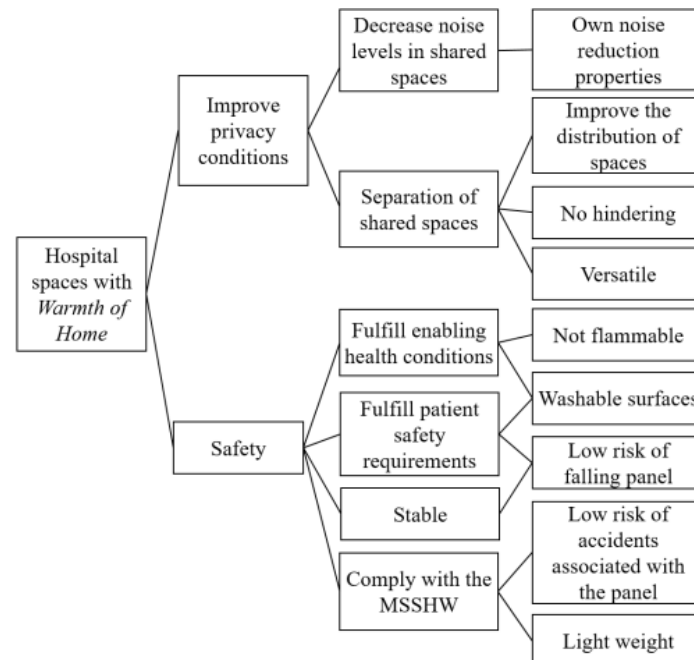


Figure 2. Goals tree of the posed problem.

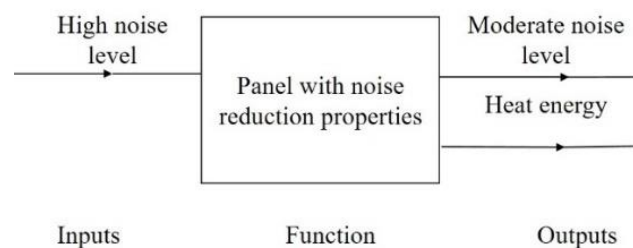


Figure 3. Black box, main function of the panel.

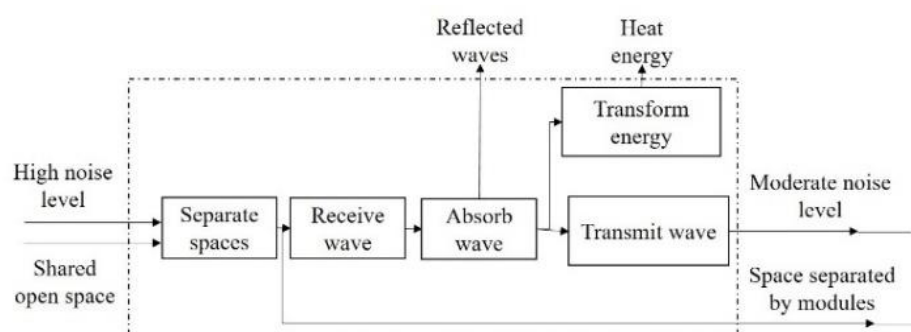


Figure 4. Transparent panel functions box.

2.3. Fixing requirements

At this stage, the emphasis is placed on the problem, and especially on the goals set out in the goals tree. For this is made a systematic search of the information regarding 5 topics: Patient Safety, cleaning and disinfection, health and safety at work, regulations for hospitals and noise levels for hospitals. From the entire search, a large number of requirements are extracted that the design of the

panel must comply with, and others that are desirable due to certain conditions; for example, all hospitals must comply with the requirements specified in Resolution 2003 of 2014, since they are the minimum conditions for health care services, however, only the ones which are accredited (or are in the process to get the accreditation in health) must cover the conditions included in Decree 903 of 2014 [9]. The same happens with the issue of accreditation by Joint Commission International, however, this covers some relevant concepts such as Patient Safety that are part of the health approach in Colombia today [10].

With the information search, about 60 requirements were collected. However, selection processes of the most determinant requirements for the design were carried out and even the requirements were reconsidered in such a way that it was possible to cover a large number of characteristics in only one. Finally, the requirements set for the design are presented in Table 1, which differentiates the requirements that demands (D in Table 1) and those that are desirable (d in Table 1).

Table 1. Requirements for the design of the panel.

Requirements	D	d
Smooth, washable and resistant to detergent / disinfectant products [11]	X	
Smooth and easy to clean contours [10]		X
Must have noise reduction properties [3]	X	
It must allow the movement of people and equipment [12]	X	
Allows separations and closings in different spaces	X	
Modular structure maximum 50 cm wide [12]		
Easy and safe to install, operate and manipulate [13]	X	
Installation by non-specialized operator		X
Obvious operation, simple and convenient handling		X
Aesthetically and visually pleasing to the hospital environment [6], [14]	X	
Possibility of customizing the panel according to institutional needs		X
Portable and with a maximum weight of 12.5 kg [13]	X	
Stable [7], [10], [11]	X	
Not flammable [11]	X	

2.4. Determination of characteristics

The stage of determination of characteristics consists of defining which are the engineering variables, which are going to be consider for the design of the panel [2]. The main input of this stage is the basic needs of the users that provide the starting point for the design process. In order to objectively obtain these conditions, the problem was presented to several users (patients, companions, health care personnel and support staff of health service provider institutions) in order to indicate the requirements that, from their perspective, could be relevant to the panel that was being designed. Thus, 22 requirements were identified and grouped according to the affinity between them (see Table 2).

The next step was to determine the engineering characteristics that are used to quantify the requirements. There were found 14 engineering characteristics (see Table 2) that can be quantified and also highlight the user's requirements in the design.

With the defined requirements and the determined characteristics, it was established a relationship between both in order to demonstrate the route that the design must take and set quantifiable goals for each characteristic. Once the information in the matrix shown in Table 2 was collected, the next stage of the design was passed, in which alternatives for product design were considered.

2.5. Generation of alternatives

For the generation of a design it is important to consider the products that are currently on the market in order to take as a reference some of the characteristics of these and generate improvements that achieve a more adequate solution in the context of the problematic raised.

For this, it was used a morphological matrix where the alternatives for each of the functions can be visualized. Thus, the first thing that was defined were the characteristics that will be explored with the alternatives presented by the products of the market. Also included the first version of the acoustic panel that is being designed as it has interesting features such as the acoustic absorbent material whose properties work for the hospital environment, unlike other materials used for noise absorption [3]. The characteristics explored were defined based on the functions and requirements of the panel, and, in turn, the means are also contextualized under the conditions of the proposed problem. Table 3 shows the morphological matrix that was constructed and, from which, different design alternatives for the panel were generated. According to this matrix, there are 32 different design options that can be presented; then, the 3 that were considered most consistent according to the requirements raised in the previous stages are presented (see Figure 5).

Table 2. Matrix of user requirements vs. engineering features.

	Contact angle	# of bacterial colonies	Absorption coefficient	Steps to install / uninstall	Time to install / uninstall	# of standard tools required	# of non-standard tools required	Panel weight	# wheels	Static floor support (brakes)	# of bodies of the structure	Width of each body	Height of each body	Flame propagation speed
Separate spaces														
Washable	X	X						X						
Decrease noise			X											
Easy to use				X	X	X	X	X			X		X	
Aesthetic											X			
Portable								X	X		X		X	
Not flammable														X
Safe								X	X	X	X		X	
Non-interference												X	X	
Units	°	#	-	#	seg	#	#	kg	#	-	#	cm	cm	$\frac{mm}{seg}$
Goal	-	0	-	5	300	2	0	12.5	12	-	5	50	200	2.2

Table 3. Morphological matrix for generation of design alternatives.

Characteristics	Ways			
Support	Floor support	Side support	Roof support	Mixed support
Portable	Folding	Rollable		
Non-interference	Flat legs	Wheels		
Reduce noise	Acoustic absorbent material			
Structure	Rigid	Malleable		

2.5.1. Alternative 1. For this design alternative, a floor support was selected through the use of wheels with brakes that make possible the stability of the panel, together with a folding and rigid structure and, using the acoustic absorbent material to confer the properties of noise reduction. This design alternative can be folded and left as a box to store it easily.

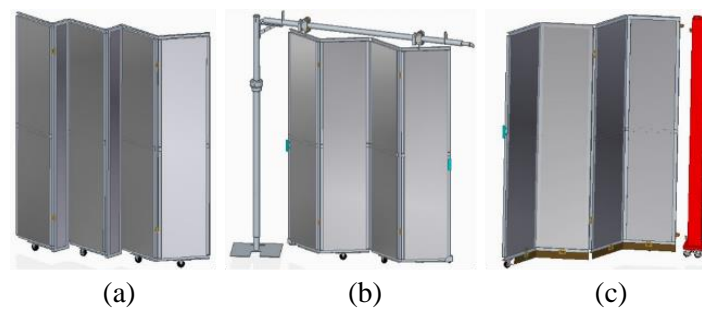


Figure 5. Design alternatives (a) Alternative 1, (b) Alternative 2, (c) Alternative 3.

2.5.2. Alternative 2. In this alternative, a mixed support with a floor and lateral component was selected. For this purpose, a telescopic system with vertical prolongation was used, in which a rail is used to give greater stability to the structure. Additionally, the floor support includes wheels to facilitate the folding of the rigid bodies of the panel. In this system the acoustic absorbent material is also used for the acoustic properties of the panel.

2.5.3. Alternative 3. A structure with mixed support is used as in alternative 2, since it involves a lateral pipe that favors the stability of the panel, and wheels with brake as support to floor and a way to improve the portability of the panel. As in the two previous designs, this also includes the acoustic absorbent material.

2.6. Evaluating alternatives

For the evaluation of the alternatives, the design alternatives proposed in the immediately previous stage and the user's requirements were taken, to which a percentage of participation had been assigned according to the affinity and the relationship of these with the objectives set out in the goals tree. The compliance scale used for the evaluation of design alternatives, considers how much the design alternative meets the requirement or not. This scale consists of giving a grade of 5 when compliance is high, 3 when it is moderate and 1 when it is low. With this scale, the qualification of each design alternative is made against each requirement and the weighted qualification of each design alternative is obtained, as shown in Table 4.

Table 4. Evaluation of design alternatives.

Requirements	% participation	Design alternatives		
		Alternative 1	Alternative 2	Alternative 3
Separate spaces	12%	3	1	5
Washable	12%	3	3	3
Reduce noise	14%	5	5	5
Easy to use	10%	3	1	5
Aesthetic	10%	5	1	5
Portable	10%	5	3	3
Not flammable	10%	1	1	1
Safe	12%	1	5	5
Non-interference	10%	5	3	5
Weighted rating		3.44	2.68	4.16

Without delving deeply into each qualification, it is important to note several details:

- The three design alternatives have as way for noise reduction the acoustic absorbent material of the first version of the panel, so that all designs have a high compliance with this requirement.

- Faced with the requirement that the product must be washable, all designs received a moderate compliance rating. This is because the design conditions are met in terms of finishes, however, a certain part of the condition that the product can be washed or not depends on the materials, for which it is necessary to make tests and define certain specifications.
- The requirement that refers to the aesthetics of the design only reflects the appearance of the structure. However, it is important to bear in mind that this component is addressed in the next stage from the issue of *Home Warmth* through the improvement of details.
- And, finally, there is the issue of the condition that the design must meet as not to being flammable. This condition depends clearly on the material, so the information of the design alternative is not a reference point for this requirement and, for this reason, it is qualified with low compliance.

For the selection of the design, it was taken the alternative with the higher score in the weighted qualification, that is, the alternative 3, with pass to the stage of refinement of the details.

2.7. Improvement of details

In this stage, details regarding the design are finalized to cover the requirements and objectives that were set for the process. At this point the materials are considered watching that the characteristics of these contribute to the fulfillment of the objectives. Another detail that is made refers to how the concept of *Home Warmth* is involved in the design. For this, was found an alternative that consists of placing a printed cover on the panel and that can be customized according to the needs of the user. This article does not report more on this stage due to the fact that there are several conditions that require a deeper study.

3. Results

We established the requirements that allow us to solve the problem detected and from these, suggest the diagrams developed by the authors that facilitates the analysis of the information obtained and that gave basis to the development of the solution proposed by the authors in this work. The design methodology was implemented, and the result was a solution that adequately fulfilled the requirements considered by the authors (see Figure 5 (B)). The acoustic panel was developed based on the needs of the hospital environment around the reduction of noise, ensuring that the patient has a warm environment without neglecting the safety regulations of the patient.

4. Conclusions

Design processes always have a subjective component contributed by the creativity of the designer; however, the objective component of the process that is achieved through the approach of the problem and the contextualization of the needs is very important. It was evidenced that by making a good assessment of the noise problem in the hospital environment and adopting the concepts of Home Warmth and Patient Safety, it was developed a solution to the problem addressed in this work through the application of the model VDI 2221 and the model of symmetry problem/solution and additionally the analysis made by the authors from the point of view of the reviewed literature, current commercial solutions and the opinion of experts this presents an innovative potential.

References

- [1] Cunha M and Silva N 2015 Hospital noise and patients' Wellbeing *Procedia - Social and Behavioral Sciences* **171** 246–251
- [2] Cross N 1999 *Métodos de diseño: Estrategias para el diseño de productos* (México: Limusa Wiley)
- [3] Rivera-Vega M, Galeano-Upegui B, Escobar-Mora N and Patiño E 2015 El proceso de diseño de una barrera acústica aplicado al sector hospitalario *Revista Ingeniería Biomédica* **9** 133–138
- [4] Yepes D, Gómez M, Sánchez L and Jaramillo A 2009 Metodología de elaboración de mapas acústicos como herramienta de gestión de ruido urbano - Caso Medellín *Dyna* **76(158)** 29–40
- [5] Mendoza-Sánchez R, Roque-Sánchez R and Moncada-González B 1996 Nivel de ruido en una institución hospitalaria de asistencia y docencia *Gaceta Médica de México* **132(2)** 127–133

- [6] Sanín J 2009 *Hogar en tránsito: entre las tácticas de la malicia indígena y las estrategias de la inclusión social* (Medellín: Universidad Pontificia Bolivariana)
- [7] Villarreal E 2007 Seguridad de los pacientes. Un compromiso de todos para un cuidado de calidad *Salud Uninorte* **23**(1) 112–119
- [8] Isbert A 1998 *Diseño acústico de espacios arquitectónicos* (Barcelona: Edicions de la Universitat Politècnica de Catalunya)
- [9] Ministerio de Salud y Protección Social 2014 *Sistema Único de Acreditación en Salud Decreto 903 de 2014* (Colombia: Ministerio de Salud y Protección Social)
- [10] Joint Commission International 2017 Section I: Accreditation Participation Requirements *Joint Commission International Accreditation Standards for Hospitals* (Illinois: Joint Commission International)
- [11] Ministerio de salud y protección social 2014 *Procedimientos y condiciones de inscripción de los Prestadores de Servicios de Salud y de habilitación de servicios de salud Resolución 2003 de 2014* (Colombia: Ministerio de salud y protección social)
- [12] Panero J and Zelnik M 1996 *Las dimensiones humanas en los espacios interiores. Estandares antropométricos* (Barcelona: Ediciones G. Gili)
- [13] Ministerio de Trabajo y Seguridad Social 1979 *Disposiciones sobre vivienda, higiene y seguridad en los establecimientos de trabajo Resolución 2400 de 1979* (Colombia: Ministerio de Trabajo y Seguridad Social)
- [14] Cuervo J 2010 ¿Vivienda, casa, hogar? La construcción del concepto "hábitat doméstico" *Iconofacto* **6**(7) 70-88