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Acoustic of open-plan offices

Relatore:

Chiar.ma Prof.ssa Arianna Astolfi

Candidato:

Riccardo Caradonna

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Abstract

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01. Abstract

In recent years, the world of work has undergone profound changes that have a significant impact on the physical spaces where people work. In the case of offices, there has been a shift from individual offices to open-plan spaces in, capable of accommodating multiple workstations. This change, in addition to generating cost savings, has led to an entirely new way of experiencing the workplace, transitioning from a more private space to a collective one.

Over the years, research has focused extensively on the subjective satisfaction levels of workers. In the field of acoustics, particular attention has been given to the detrimental effects of Irrilevant Speech Noise (ISN), a parameter that defines the level of noise generated by conversations among workers, phone calls, and other noises they produce. It has been shown that this ISN negatively influences cognitive performance, physical and mental health, and productivity of those working in such offices. Studies by Haapakangas et al. (2008), Pejtersen et al. (2006), and Danielsson (2005) have demonstrated a correlation between the disruption caused by Irrilevant Speech Noise and phenomena such as absenteeism, hearing problems, discomfort, and difficulty in maintaining concentration.

The purpose of this thesis is to provide elements for the design of open-plan offices in order to ensure maximum acoustic comfort. The indicators describing the acoustic quality of an office are specified in the UNI ISO 3382-3:2022 standard. These descriptive parameters include:

- D2,S, which is the spatial decay rate of A-weighted speech sound pressure level (SPL)
- Lp,A,S,4m, which is the A-weighted sound pressure level at 4 meters
- Lp,A,B, which represents the A-weighted background noise level
- STI (Speech Transmission Index)
- rD, which is the distraction distance

During the initial phase of this research, measurements of the aforementioned parameters were conducted in three different offices at the Intesa San Paolo headquarters in Milan. The measurements were performed following the procedure described in the reference standard UNI ISO 3382-3:2022. Once the measurements were taken, the data was analyzed and the results showed poor acoustic quality in these open-plan offices. Most of the values found did not fall within the optimal ranges provided by the standard.

The next step involves designing elements to improve the acoustic quality of these environments. To achieve this, the acoustic simulation software Odeon was utilized. By modeling the spaces of interest, the software allows us to simulate acoustic measurements and provides the parameters described in the standard. This enables us to assess the effectiveness of improvement interventions.

Regarding office space design, a bibliographic research has been conducted on the trends of modern offices. This research has provided useful insights for rethinking these spaces and has been a source of ideas for designing furniture elements that also have acoustic functions, such as movable partitions and sound-absorbing elements.

The project is based on the quantity of absorbing surface area, absorption coefficients of materials and the use of acoustic elememts like baffle, screen and cubicles. The combination of these elements and their precise design allows us to significantly alter the acoustic conditions of the environments, aiming to achieve the optimal values described in the standard and providing an environment of optimal acoustic comfort.

In conclusion, it is demonstrated that acoustic parameters can be improved through conscious design that maximizes the sound-absorbing power of materials, utilizes acoustic elements, and considering the functional requirements demanded by the work environment.

Open-space offices

02.1 A brief history
02.2 Offices today
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02. Open plan offices

The term “open office” is widely used nowadays and represents a type of modern work environment; however, this kind of space originated in the early 20th century.

The open office concept has multiple nuances of meaning, even though they all represent a type of space with specific characteristics, such as the absence of dividing walls, the presence of individual or multiple workstations, and the sharing of workspace. Professor and researcher Hongisto Valtteri[1] defines different types of work environments. Based on their configuration, we find private offices, shared offices (able to accommodate from two to five people), and open offices, spaces capable of hosting more than five workstations within them.

Another definition of an open office can be found in ISO 3382-3 2022[2], which describes it as a large open space where a significant number of occupants can work simultaneously at defined workstations.

Caroline Bernie[12] defines the open office as a space “*where walls and partitions have been removed and have been replaced with other instruments such as cubicles, plants, and furniture to give the sense of separating departments and teams physically.*”

We can then provide a concise description of the characteristics that distinguish an open office. We refer to a workspace that doesn't include physical barriers like walls or small rooms, thereby promoting a collaborative environment. The configuration often consists of clusters of desks that can accommodate multiple workstations or serve as common spaces for group work. The variability of configurations creates a dynamic space capable of adapting to different work situations, offering more or less privacy depending on the task at hand.

The popularity of this solution is driven by the positive impact it has on the work environment: it fosters collaboration among colleagues and the exchange of ideas, fundamental elements in certain work settings. This solution also provides an economic benefit, as creating these environments is much more cost-effective, in terms of workers, compared to individual office setups.

02.1 A brief History

The emergence of an office type that could be defined as open space, albeit with distinct differences from the modern concept, dates back to the early 20th century. The expansion of the industry led to an increase in the number of workers and a consequent need for space. This gave rise to the necessity of designing work environments where the differentiation between spaces for executives and workers was immediately visible. The advent of Taylorism redefined production and efficiency concepts, leading to changes in worker spaces, and workstations were grouped in large open areas, the early open office spaces. During this phase, workstations were placed side by side in long rows, allowing direct oversight by management; the well-being of workers was not prioritized[4].

The first to envision open workspace designs that considered workers' needs was Frank Lloyd Wright; in the 1920s, he redesigned the Larkin Administration Building, taking into account acoustics and lighting as key elements for workers' well-being[3].

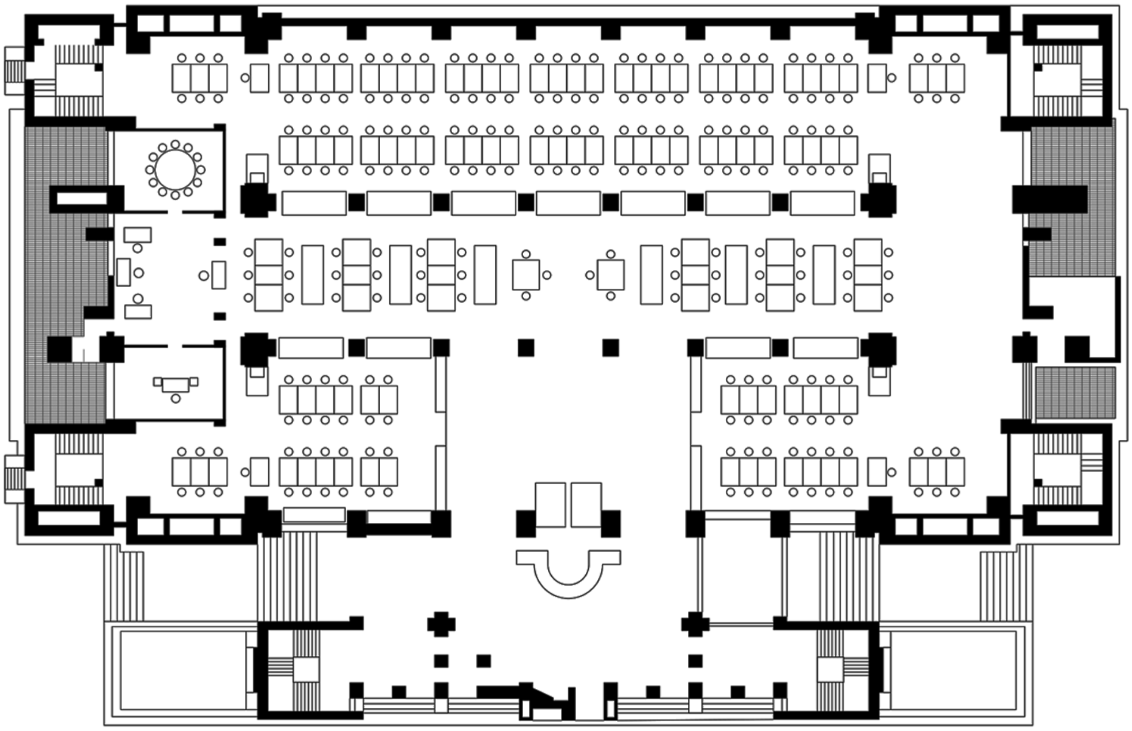

Figure 1 *First floor of Larkin Administration Building, 1904-1945, Frank Lloyd Wright*

In Europe, in 1950, a new way of conceiving open office design emerges: the Burolandschaft. This type of design focuses on the flexibility of spaces and the natural pathways that workers take within the workspace. The aim of this approach is to enhance communication among workers, making the working experience even more social[5]. The design of these spaces is developed by observing and mapping workers' movements, in order to facilitate communication and workflow. Another effect of this kind of design is the elimination of any form of hierarchy within the work environment, equalizing the spaces of executives with those of workers.

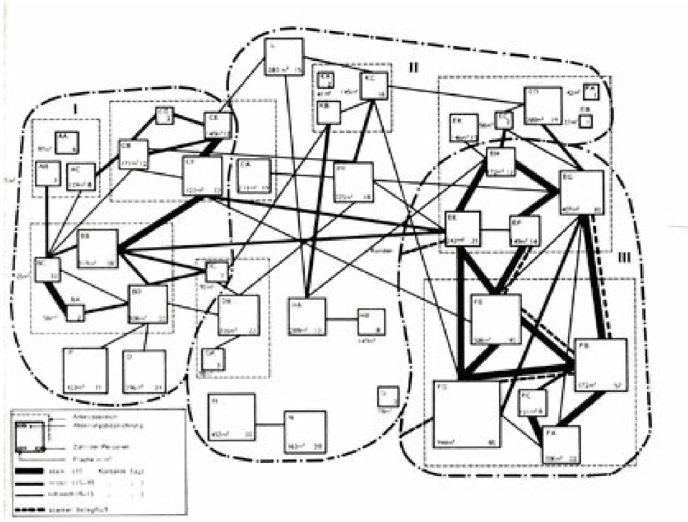

Figure 2 *Diagram of relation of a corporate with 800 people.*
From: Ottomar Gottschalk "Flexible Verwaltungsbauten", Verlag Schnelle, Quickborn 1968, grafica: Karin Eckl

The desire to create workspaces with varying levels of privacy led, in the 1960s, to the emergence of the Action Office. This project was conceived by inventor Robert Propst and involved a series of modular furniture elements that could create different space configurations: open, semi-enclosed, or enclosed[6]. The installation of these modular panels allowed for the creation of work areas with different functions, thereby moving beyond the extreme concept of Burolandschaft and enabling a broader range of possibilities for designing workspaces.

Figure 3 *Action Office, 1970, USA*

In the 1970s, offices are increasingly recognizing the need for spaces for individual workers that provide a certain level of privacy. The development of the partition technology introduced by the Action Office led to the emergence of the so-called ‘cubicle offices’ in the 1980s.

Open offices lose those principles of interaction and communication among workers in favor of a series of individual workstations placed side by side and separated by lateral and frontal dividers. This configuration allowed greater privacy for individual workers, isolating them from external involvement. The space is standardized in this way, enabling significant cost reduction; each workstation consists of a desk and three partitions, one frontal and two lateral.

Figure 4 *Typical Cube Farm office configuration*

02.2 Offices today

In response to the closure of cubicle offices, the 20th century witnessed a reopening towards a design concept of open space, devoid of distinct separations, promoting exchange and interaction among workers.

English architect Francis Cuthbert Duffy, in his book “The New Office”[8], describes this phase as ‘the new way of working,’ referring to the change occurring in work environments.

The advent of new technologies, such as increasingly portable mobile devices and fast connections, has allowed work to extend beyond the office. This shift has led to the fading of fixed workstations in favor of spaces that can serve various functions. Today, most offices require and equip themselves with flexible spaces, accommodating varying numbers of people, with the goal of sharing ideas and projects.

Modern large companies, particularly in the technology sector, endorse this type of workspace. According to a 2008 study by Gensler research firm, leading companies in their field spend 23% more time on employee collaboration compared to their competitors and consider this a key to their success[9].

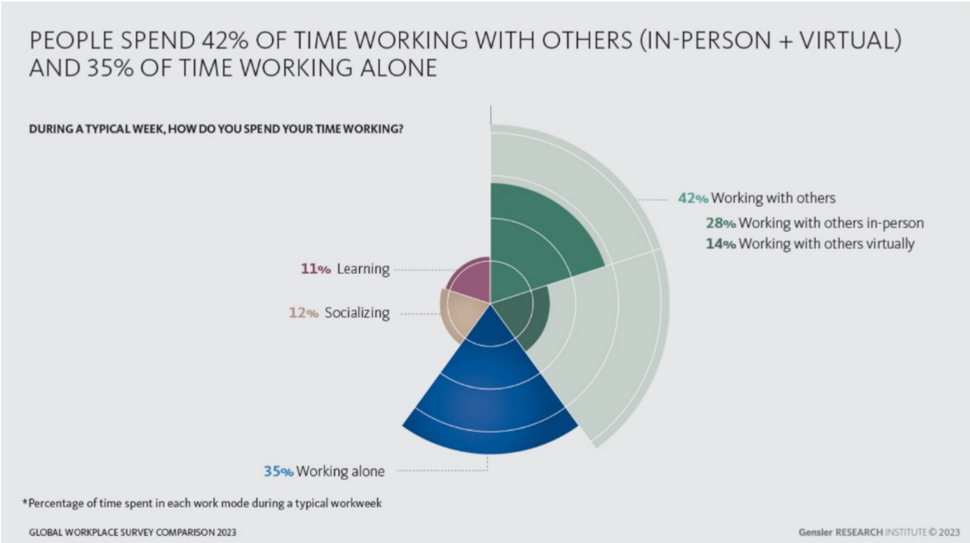

Figure 5 *Gensler's research results, 2023*

In a 2008 interview with Brad Bird, the CEO of Pixar, he stated: "*Steve [Jobs] put the mailboxes, the meeting rooms, the cafeteria, and, most insidiously and brilliantly, the bathrooms in the center—which initially drove us crazy—so that you run into everybody during the course of a day. He realized that when people run into each other, when they make eye contact, things happen. So he made it impossible for you not to run into the rest of the company.*" [15]

A recent study conducted by Gensler in 2023 confirms this trend, asserting that globally, workers spend 42% of their time working in groups compared to 35% of their time working alone[16].

The research further anticipates that spaces for non-work activities, referred to as "Unproductivity spaces," should be integrated to workspace design, as they are essential for worker well-being. Gensler argues that: "*There's a perception that being unproductive is time spent not contributing to the bottom line or even professional growth. Casual conversations with your colleagues and mentors, project completion reflections, self-driven learning, and taking a moment for well-being are, by definition, unproductive. These moments are vital to how people and businesses grow, professionally and personally. Unproductivity is innately human. It is unintentional, expansive, and often open-ended.*"[17]

Key considerations in open workspace design are multiple and reflect modernity and primarily the needs of workers. A study in the Journal of Corporate Real Estate[11] identified the main parameters that some of the largest Australian architecture firms take into account for open office design.

One primary aspect considered is the cultural context of the specific company. Often, the configuration of a space aims to be the company's first distinctive symbol, making designing the layout a means of conveying the message the company wants to project.

Designing a space while respecting the generational gap among workers creates an environment favorable to all, fostering valuable connections between different generations within the company.

Flexibility is a crucial feature when designing a workspace. A flexible open space can accommodate future changes a company might undertake, whether they are technological improvements or shifts in strategy. Flexibility is also required within workspaces to ensure diversity in work activities. Mobile partitions, modular furniture, and adaptable meeting rooms allow for a variety of work functions within the workspace, even on a daily basis. The theme of flexibility also arises when innovative technological structures are incorporated into the design.

Other necessary aspects considered in the design include acoustics, lighting, and furniture. For acoustics, absorbent materials are used to prevent noise diffusion, aiming to meet the comfort levels defined by regulations. Lighting requires studying optimal light contributions and how they propagate within the workspace. The use of colors to paint walls also significantly affects worker comfort. The use of specific furniture for creating flexible spaces allows for notable variability in workspace configuration.

Open offices can be organized in different configurations while maintaining their primary function of promoting collaboration among individuals. Co-working spaces, for instance, are open office environments where various workstations can be occupied by freelance workers who rent the workspace. The proximity of professionals, even from different fields, can facilitate valuable information exchange for workers. The term “co-working” originated in the early 2000s. In 2005, Brad Neuberg founded the first co-working space in San Francisco, California, describing it as a place for independent workers[21].

Figure 6 *Space of coworking*

Another type of open office configuration is the Activity-Based Office Layout (ABW); in this case, the space is divided into thematic areas, and workers have the option to move to the area that suits the type of work they need to perform. While open space remains, this kind of zoning is visible through the arrangement of individual and multiple workstations and the presence of lightweight barriers.

Figure 7 *Open-space Activity Based Work*

The rapid pace of technological advancements and the emergence of innovative work realities make it challenging to predict the future development of workspace design. It is easily foreseeable that technology will enable remote work, transforming the workspace into a place for meetings and idea sharing. This shift will lead to a reduction in fixed workstations and large screens in favor of collaboration spaces. Artificial intelligence will play a significant role in these new spaces, catering to the needs of those who gather in these shared places.

As people increasingly work from home, the office will become a hub for collaborative processes and idea generation.

Sustainability will be a prominent feature of future offices, involving the use of natural light and air, reduced resource wastage, and materials with low environmental impact.

An emerging phenomenon is the “Hoffice,” where individuals host a small group of collaborators at their home for a few hours or days to promote group work. This approach could decrease commuting and turn the domestic environment into a pleasant workspace.

In connection with this phenomenon, the creation of smaller satellite offices that can accommodate restricted work groups becomes plausible. Through technology, these distributed offices can remain in constant communication with a central headquarters, reducing the need for certain workers to commute.

02.3 Pros and Cons

Open offices offer an opportunity for companies looking to invest in staff communication and teamwork. The choice of this workspace configuration presents both advantages and disadvantages.

An economic benefit of opting for an open office is that constructing a space without partitions, forming a single large area, incurs much lower costs compared to traditional offices. Additionally, this configuration can accommodate a larger workforce.

Open offices facilitate movement, enhancing communication among employees. Encouraging idea exchange is the most significant advantage of this configuration: communication translates to creativity, productivity, and innovation. Teamwork is also easier in an open space environment, as individuals naturally form groups to solve common problems and achieve set objectives[13].

Negative effects in open workspace environments are related to comfort and privacy concerns. Reduced productivity can result from continuous movement and distractions caused by nearby individuals when a worker needs to concentrate. However, a study by Ethan Bernstein and Ben Waber[14] demonstrates that workers often mitigate this effect by creating a “fourth wall,” isolating themselves from the rest of the office using headphones. This way, privacy and concentration are maintained even in an open office.

Noise represents a significant disturbance factor in open offices, affecting the concentration of those working within and causing distraction and stress. The lack of direct control over the temperature can also discomfort workers. However, proper structural and furniture design can significantly contribute to reducing negative effects caused by noise.

The absence of private offices raises two additional issues: first, a health concern related to increased pathogen transmission due to increased interactions among people. Second, a sense of homogenization arises as the lack of a dedicated workspace prevents personalization, generating a loss of identity in the work station[15].

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Human needs

03

03 Human needs

In Chapter 2, in its concluding section, we saw how the needs of modern workspaces are diverse and constantly changing. This requires the designer to have a deep understanding of the work that takes place within a specific space, the company's identity, and, most importantly, the needs of those who work within that space. Analyzing these elements allows us architects to anticipate and channel the rapid changes in the world of work effectively, with the aim of creating spaces that ensure the well-being of workers.

Designing a workspace that promotes the well-being of those who inhabit it becomes a multidisciplinary practice that involves the participation of specific professionals who can understand all the needs that go beyond the architectural context. It is therefore advisable to involve specialists such as psychologists and experts in psychophysical well-being in the design process[1].

03.1 Different people, different needs

Within a workplace, whether it's an office or a factory, you can find a wide range of ages among the employees, creating what we often refer to as a generational gap. Recent literature has formally categorized different generations, describing their general characteristics. Of course, these clear-cut divisions don't precisely represent the diversity within each generation, but they offer a useful distinction for defining heterogeneous groups of people. This categorization, starting from the post-war period, divides generations based on social and historical events and contexts, such as the end of the Cold War, economic recessions, the September 11 terrorist attack, or the Arab Spring[2].

The key concept underlying this division is that a group of people belonging to the same generation, due to shared historical and cultural experiences, may share certain attitudes, values, and behavioral tendencies[3]. The generations identified in the literature are numerous, but they can be summarized as follows:

1. Baby Boomers, born before 1965, nearing retirement, described as dependable and loyal, carrying the most historical knowledge but often less dynamic and resistant to change[4].
2. Generation X, born between 1963 and 1980, children of economic prosperity with higher education levels and greater familiarity with technology[5].
3. Generation Y, born between 1980 and 1995, characterized by a focus on family and career values, technological advancements, and being the first generation to be familiar with environmental impact concepts.
4. Generation Z, those born between 1995 and 2012, still relatively few in the workforce; this generation is the first true digital native generation, growing up

in the era of social networks with a heightened awareness of environmental issues[6].

These distinctions have less defined boundaries in reality and do not always accurately reflect the values of a particular generation, especially when analyzed solely from a work perspective. The fundamental issue is that the proper design of a workspace must accommodate people of different ages, values, and principles, and the designer's goal is to capture all these differences and ensure that the coexistence of different generations becomes a value and an opportunity in the workplace environment.

Now, let's try to understand the needs that a person has in the workplace. To do this, we can use a study conducted by the architect Amos Rapoport[7], one of the founders of Environment-Behavior Studies. He argues that there are three levels of needs for each employee, categorized as low-level, mid-level, and high-level.

The low-level needs are described as the most immediate, represented by needs that can be measured and immediately perceived. In this category, we can include lighting, air quality, temperature control, acoustics, ergonomics of furniture, and contact with nature.

The mid-level needs require deeper investigation because these needs are not measurable but require greater attention and more specialized figures to identify them. One of these elements is the sense of control that a worker feels within the work environment, which can be connected to territoriality, involving familiarity with workspaces, such as one's own workstation. Another critical factor is the level of privacy, defined as the ability to control interactions within a work environment. Just as privacy, an appropriate level of socialization must be considered as a mid-level need. Lastly, autonomy, or the degree of independence with which a worker performs a given task, is another parameter that should be guaranteed.

The highest level of needs encompasses those related to elements that affect the values, culture, and beliefs of the workers. These factors contribute to what can be defined as the organizational culture of a company, which defines its fundamental values. Corporate culture is a strong element that strongly characterizes a work environment and, when well-designed, even in its symbolic elements, becomes a source of strength.

Two design elements contribute to this direction. The first is physical proximity, meaning the level of contact between users of a particular space. This increases connections between people and ensures the transmission of not only information but also values and knowledge. The second element is the definition of the workspace, specifically the layout of workstations and non-work areas. For example, an egalitarian and monotonous workstation arrangement represents a desire for control by the company, while a more open layout reduces hierarchy and enhances a sense of community and exchange.

All these categorizations should not be interpreted narrowly but are intended to facilitate the understanding of the complexity of the needs necessary for designing an environment that promotes the well-being of workers.

03.2 Different tasks, different spaces

In addition to the needs of the workers, the requirements of the companies also demand careful planning. It's often necessary to delve into the foundational values, history, and the type of image a company wants to project. Creating a workplace that aims to accommodate a group of creatives is very different from designing one focused on cybersecurity. For this reason, understanding the type of tasks that will be carried out in a certain space is essential for its design.

As described earlier, having a clear corporate culture and making it evident in the project represents a vital factor for the company's growth and development. A study conducted by Cameron, K. S., and Quinn, R. E. in 2016[8] proposes four dimensions of work, each of which is expressed differently through the configuration of the workspace.

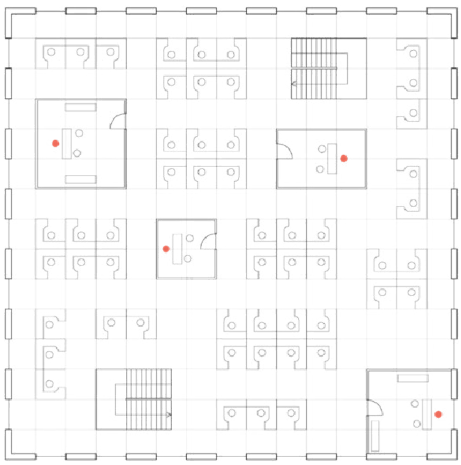
The first dimension represents a culture of control, where work is done in a non-collaborative manner, and everything is closely supervised; a strong sense of hierarchy permeates this environment.

The second dimension is the Market one: "The term market is not synonymous with the marketing function or with consumers in the marketplace. Rather, it refers to a type of organization that functions as a market itself. It is oriented toward the external environment instead of internal affairs. It is focused on transactions with (mainly) external constituencies such as suppliers, customers, contractors, licensees, unions, and regulators. And unlike a hierarchy, where internal control is maintained by rules, specialized jobs, and centralized decisions, the market operates primarily through economic market mechanisms, mainly monetary exchange[8]."

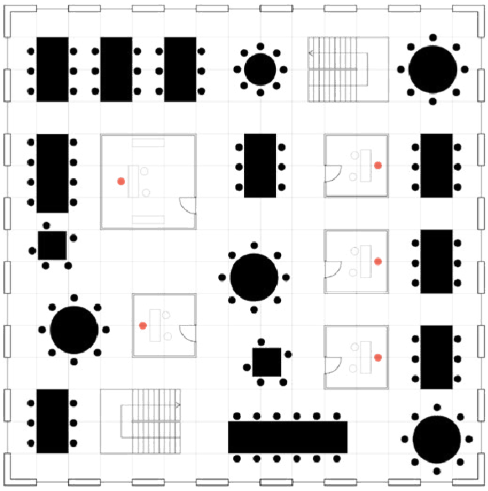
The third dimension is the creative one; its primary goal is to develop new products. For this reason, it is based on creativity, teamwork, and the almost complete absence of hierarchy. This involves the presence of group workstations but also individual workstations for specific tasks.

The last dimension is the clan, where collaboration is the fundamental principle of space organization. Teamwork and the growth of the workgroup are promoted and rewarded. This type of work requires a dynamic space that allows fixed or semi-fixed groups to work together and interact with each other.

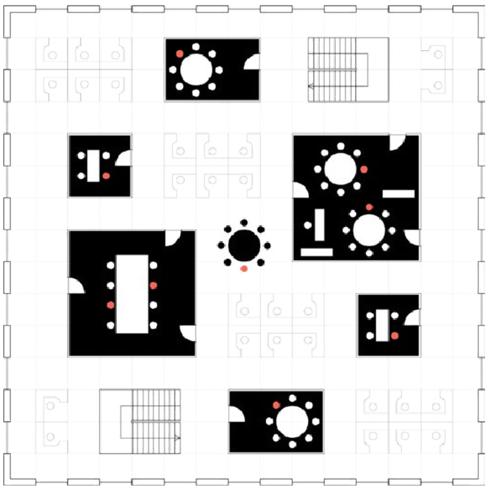
Below are four possible configurations for an open-space office that reflect the four dimensions just described. The images are from the thesis of the architect Iacopo Predieri[1], who assisted me with his work in formulating these concepts.



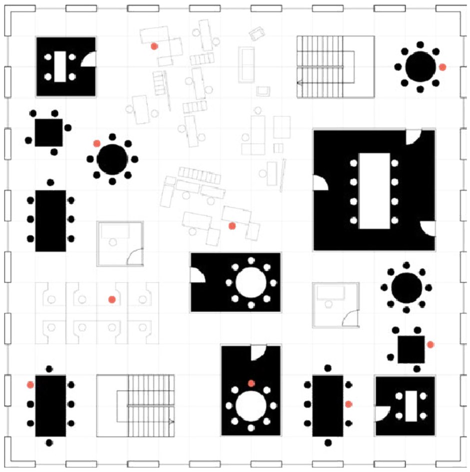
Control (Hierarchy)



Compete (Market)



Create (Adhocracy)



Collaborate (Clan)

The choice of these arrangements and their hybridizations demonstrate how the selection of a configuration, but even more so, the initial stages of design, must take into account all these elements and consider the importance of human needs and those of the company in contributing to the creation of a workplace with well-being and efficiency as the ultimate goal.

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Acoustic correction solutions

04

04. Acoustic correction solutions

04.1 Sound absorption

The quality of a work environment must also be achieved through the acoustic design of that specific space. When we talk about offices or work environments in general, we refer to places where people spend a significant part of their day, and for this reason, the quality of the work environment must be as high as possible. Many psychological studies, such as those by Professor Edem M.J.[1], Professor V. Hongisto[2], and Professor E. Trocka-Leszczynska[3], link conditions like stress to poor workplace quality and demonstrate how proper acoustic design of a work environment is crucial for the well-being of employees.

The acoustic design of an office primarily involves controlling surface absorption. The goal is to use materials that absorb sound energy, preventing its unwanted transmission in the work environment. This control encompasses both sound levels and frequencies, selecting materials that absorb certain frequencies better than others. For example, special attention should be given to low frequencies as they carry more energy and are therefore more disruptive.

Material selection becomes a crucial aspect of design, considering the material's absorption coefficient α. This coefficient represents the amount of energy absorbed at a specific frequency and can range from 0 to 1. An absorption coefficient of 1 means that the material absorbs all incident energy at that frequency, while a coefficient of 0 describes a material that reflects all incident energy at that frequency.

All materials have an acoustic absorption value that defines their absorption class. This classification is defined by the EN ISO 11654[4] standard, which defines the absorption coefficient αw and absorption classes (see Table 1).

α_w	**Sound absorption class**
0.00 - 0.05	*very bad - N.C*
0.05 - 0.20	*bad - E*
0.20 - 0.40	*poor - D*
0.40 - 0.60	*fair - C*
0.60 - 0.75	*good - B*
0.75 - 1.00	*excellent - A*

Table 1 *Class of Sound absorption*

The principles by which a system absorbs energy primarily fall into three types:

- Porous Absorption: Incident sound energy is transformed into heat by vibrating within the micro-cavities of a porous surface. The absorption frequency of this porous material varies depending on the size of the pores.
- Cavity Resonance Absorption: This system consists of a non-porous perforated panel placed at a distance from the wall to which the panel is applied. This creates a mass-spring system that absorbs incident energy at a certain frequency. This system is more frequency-selective as it works well within a narrow bandwidth.

- Panel Resonance Absorption: With this system, a panel is installed at a minimal distance from the wall. When struck by sound energy, it vibrates at a certain frequency due to its elasticity, thereby dampening and dissipating the sound energy. This system is also highly frequency-selective.
- The acoustic design of a work environment primarily acts on existing surfaces, including the floor, ceiling, and walls. In addition, it also works with furnishing elements that have a role in regulating the acoustics of the environment.

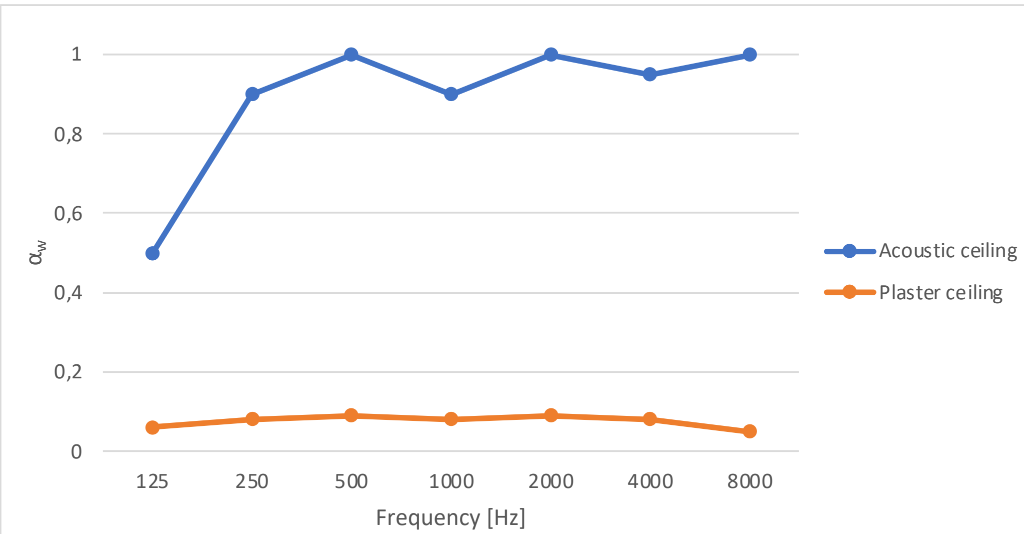
04.2 Ceiling

The ceiling, being a large and smooth surface, often acts as a significant sound reflector. Making this surface less reflective and more absorptive is one of the initial steps to take for acoustic correction of a space.

There are two main solutions: the first is the construction of an acoustic suspended ceiling, and the second, which is less effective, involves adding absorptive acoustic elements attached to the ceiling, known as baffles.

The presence of suspended ceilings is common in offices for technical reasons, which is why the use of acoustic suspended ceilings is a solution often employed in such environments. Below is an example of an acoustic suspended ceiling model from the company Ecophon, along with its absorption data in comparison to a ceiling simply covered with plaster. The model is the modular suspended ceiling Ecophon Focus A.

125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	α_w	Absorption class
0.50	0.90	1	0.90	1	0.95	1	1	A



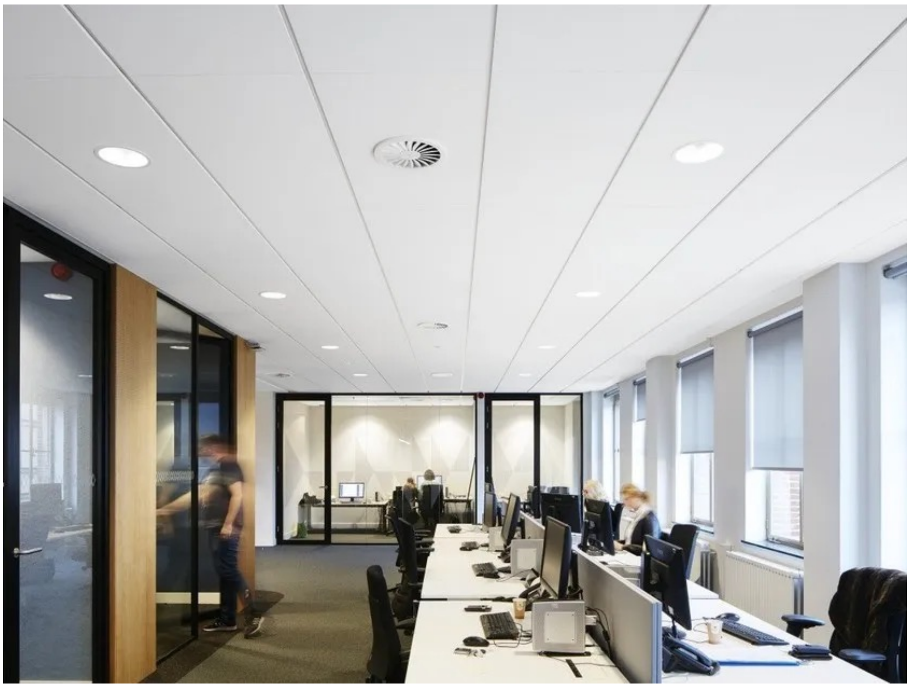


Figure 1 *Example of acoustic false ceiling*

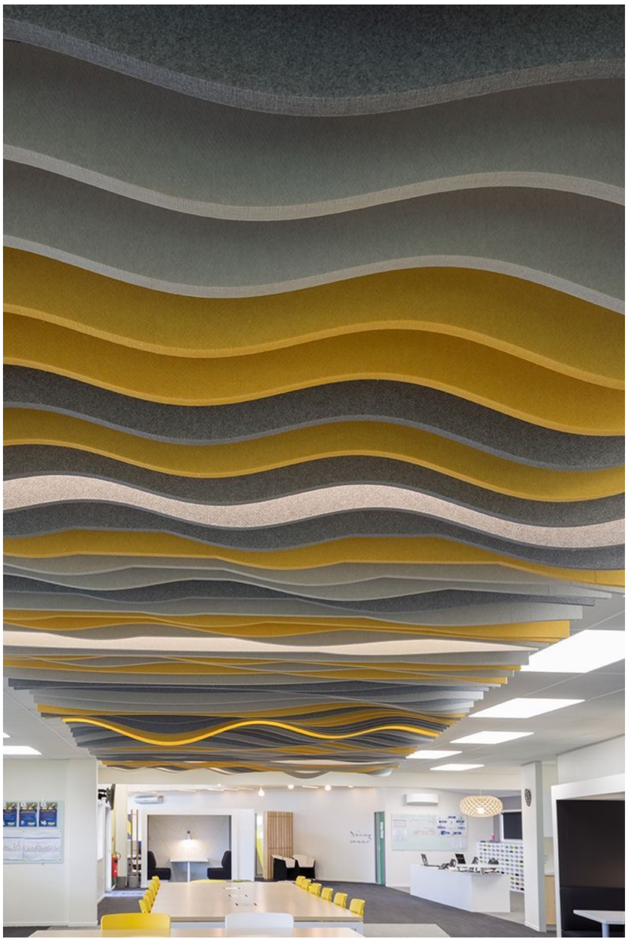


Figure 2 *Example of acoustib suspended baffle ceiling*

04.3 Walls

For walls, due to their irregular shape and surface, the most effective acoustic solution is the use of acoustic panels. These panels have defined shapes, often rectangular, and are modularly attached to the walls. The arrangement of these panels on the wall is flexible, as the acoustic absorption is primarily influenced by the total surface area of the panels.

Below are the characteristics of a panel produced by the company Ecophon, known as Akusto Wall A. The graph illustrates the absorption coefficients of the acoustic panel in comparison to a plastered wall.

125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	α_w	Absorption class
0.20	0.70	1	1	1	1	1	1	A

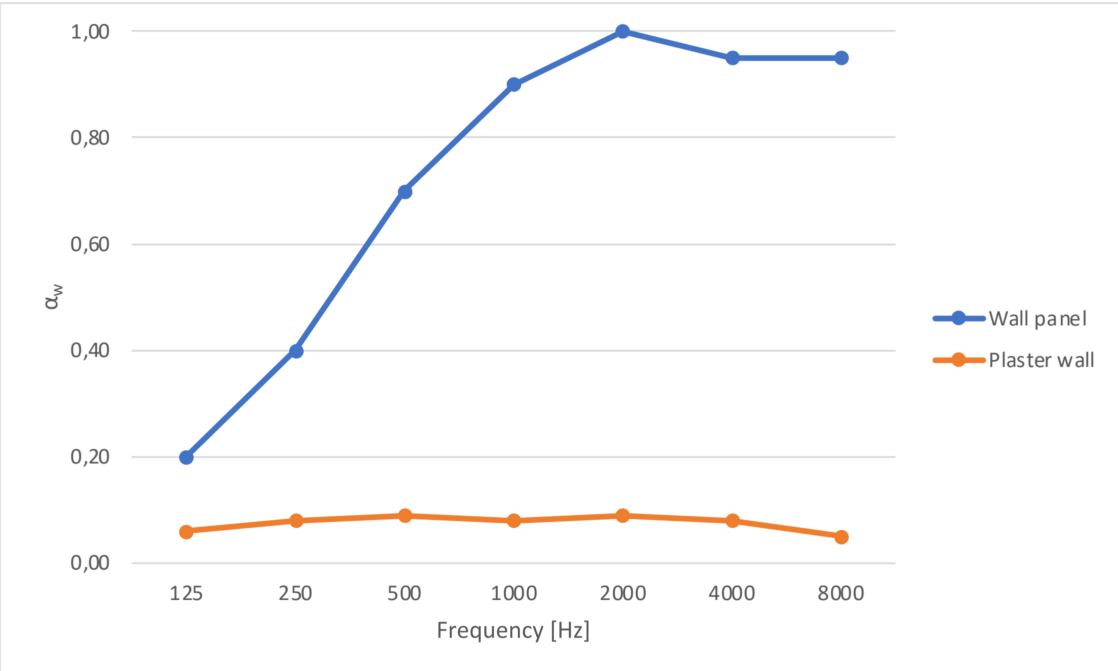


Figure 3 *Example of acoustic wall panels*

04.4 Screen

The term “screen” refers to all those elements that serve to shield sound by absorbing a significant portion of its energy. These are sound barriers that increase the sound pressure level decay in a room. We have two types of screens: desk-mounted screens and stand-alone screens. The former are panels of absorbing material that attach to the desk, dividing workstations, while the latter are divider elements that start from the floor and separate two spaces.

In both cases, due to their lightweight and versatility, these elements can be moved and installed according to various needs. This creates a dynamic space that can be more or less private depending on how the screens are positioned. The material used for these elements is very similar to wall panels, thus offering similar absorption values.

Numerous studies in the literature, including the well-known ones by Professor V. Hongisto, have investigated the effectiveness of these screens in relation to their height from the floor. The result of these studies[5] indicates that the most effective height for reducing sound pressure levels while maintaining a height that doesn't overly obstruct brightness is between 1.5 meters and 1.7 meters. This demonstrates that within this range of measurement, there are no significant differences in the attenuation of sound pressure levels.

An evolution of these two elements forms individual workstations that are enclosed on three sides; they can be referred to as cubicles and provide a workstation with a high level of privacy.

Below is an example of a stand-alone screen along with its respective absorption coefficients. This is the Ecophon Akusto Screen model.

125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	α_w	Absorption class
0.20	0.40	0.7	0.9	1	0.95	0.95	0.75	A

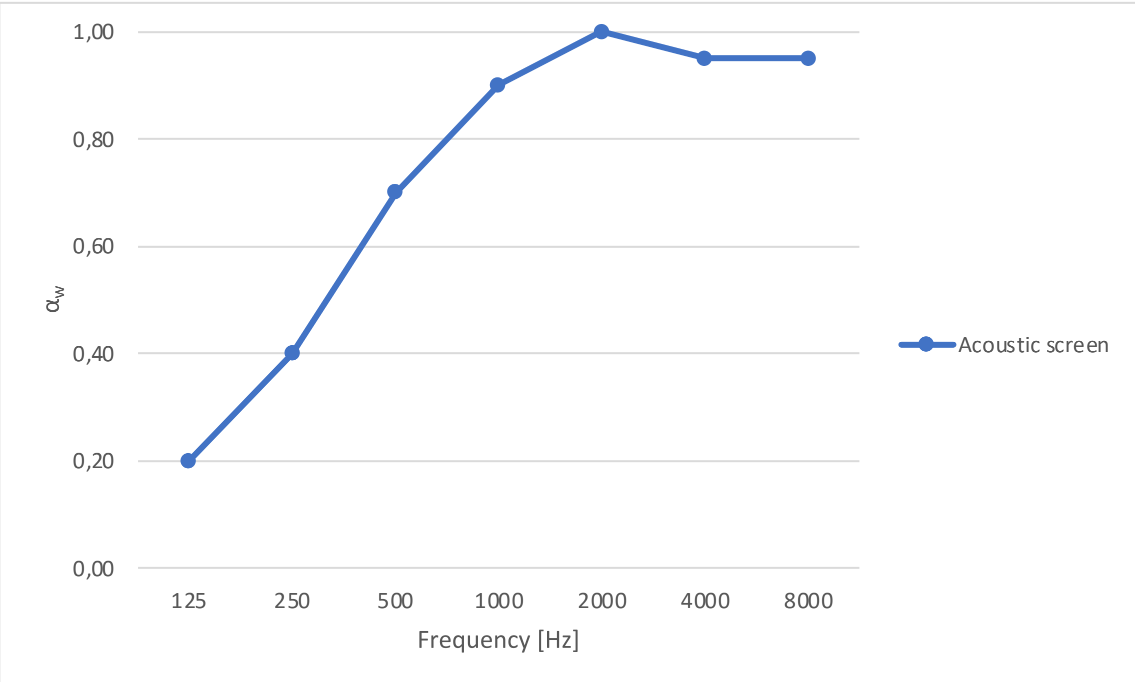


Figure 4 *Example of acoustic screen stand-alone*

Figure 5 *Example of acoustic screen desk*

Figure 6 *Example of acoustic desk cubicles*

04.5 Furniture

There is another option for adding absorbing acoustic material to better adjust acoustic parameters, such as the use of furniture items made from absorbing material. With these elements, it’s possible to increase the total absorbing surface area of the room by introducing useful items like chairs, dividers, benches, sofas, or aesthetically pleasing furniture. In this category, we can also include dedicated enclosures called phone booths, which are small acoustically isolated rooms where video calls, private phone conversations, or intense work sessions can take place in complete privacy.

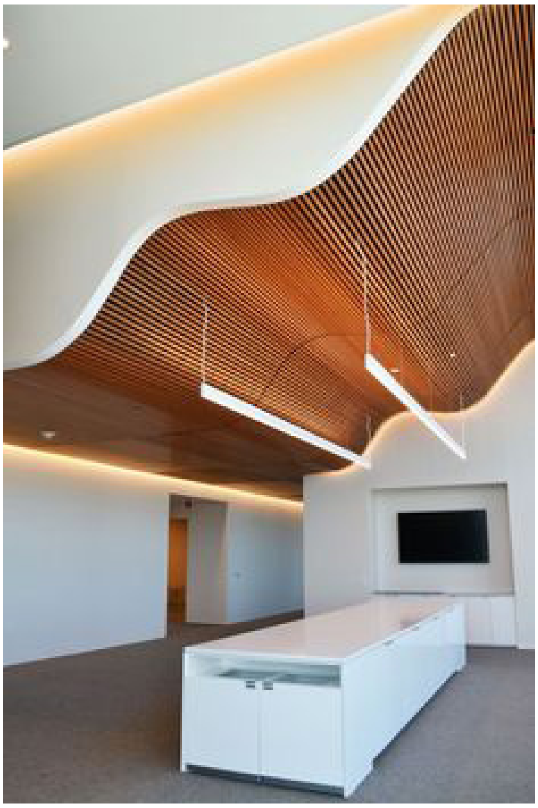
Another piece of furniture is the cocoon acoustic chair, a chair or small sofa covered with an absorbing material structure. The purpose of these furnishings is to create spaces with a higher level of privacy compared to an open-space office, allowing for specific tasks that require a greater degree of intimacy.

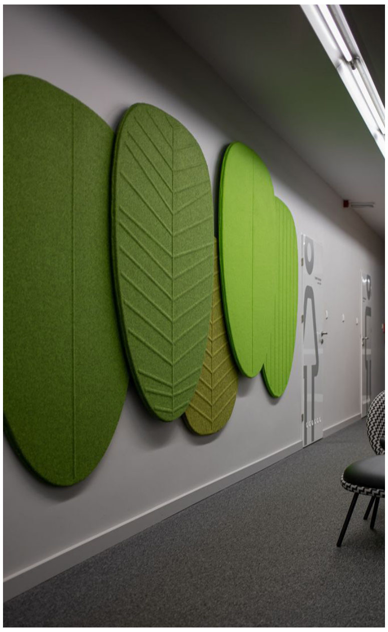
Figure 8 *Example of acoustic chair and phone box*

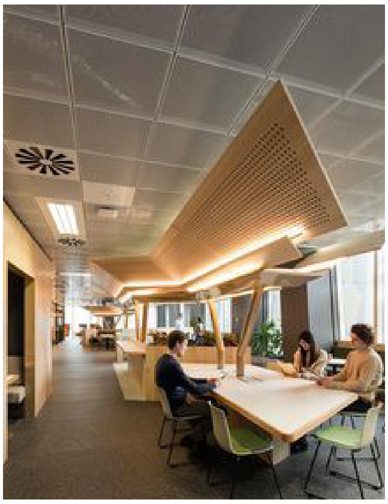
Figure 7 *Example of acoustic furniture like seating spot*

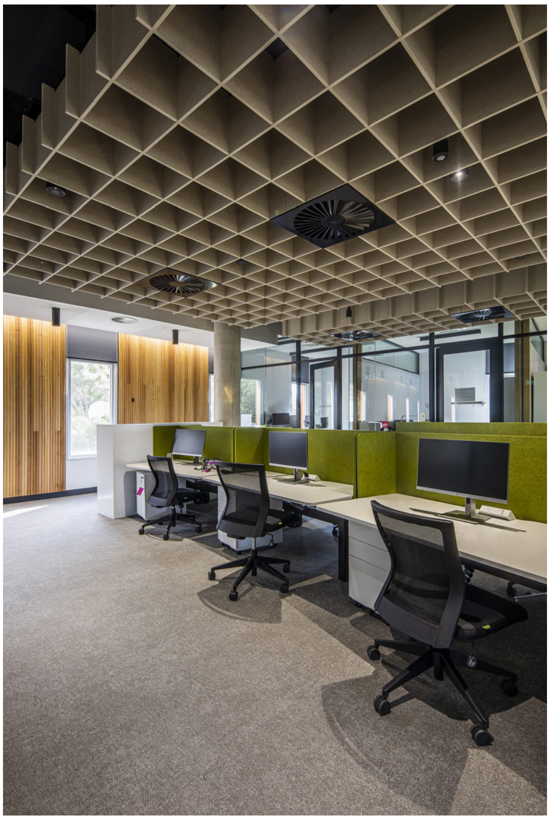
04.6 Suggestions

Below are a series of images showcasing all the elements described in the chapter, which served as inspiration for designing the elements to be incorporated within the Intesa Sanpaolo office.









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Sitography

10. https://www.ecophon.com/it/

Intesa San Paolo Offices

05

05. Intesa San Paolo Offices

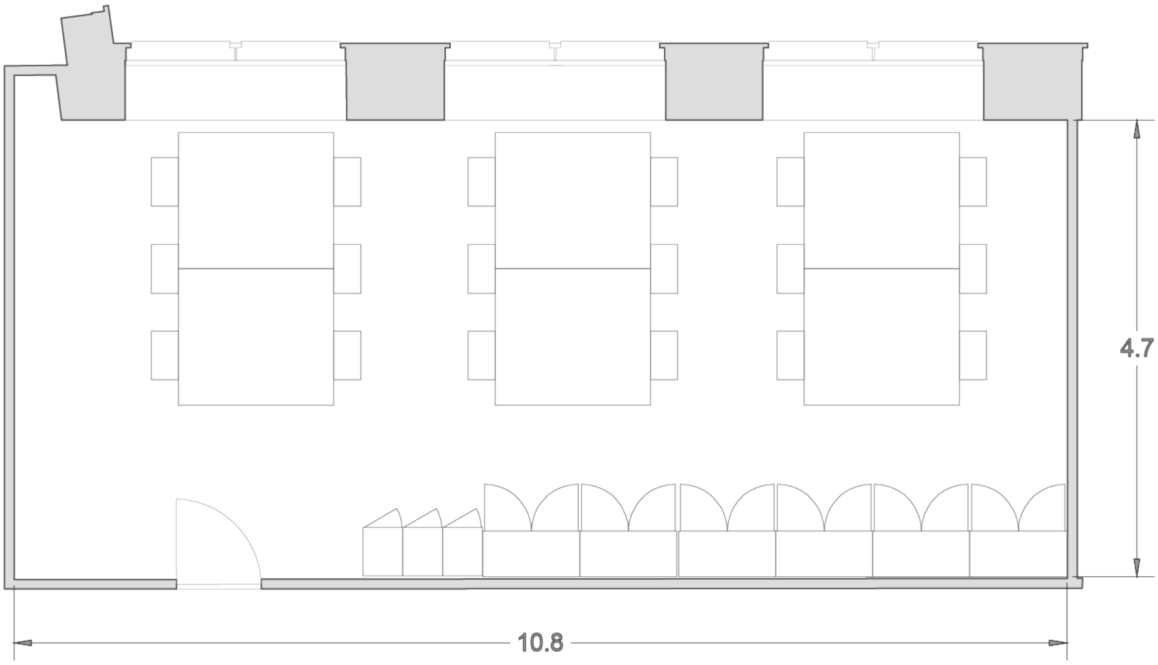
For this hesis, the offices of Intesa Sanpaolo's Milan headquarters have been chosen as case studies, with which there is also a collaboration on other research topics related to thermal comfort.

The building that houses the three selected offices is located in the center of Milan, at Piazza Paolo Ferrari 10. It's a headquarters with numerous offices inside that serve various functions. The offices under consideration are situated on the first and sixth floors and exhibit different configurations. All the offices have a similar number of workstations, around twenty, and consist of spacious desks that accommodate up to six workers each. In two offices, the desks feature low longitudinal dividers, approximately 20 cm high, while the other office has no dividing elements between workstations.

The three offices are:

- 0037 Community, on the first floor
- 0026 Bench, on the first floor
- 0001 Audit, on the sixth floor

05.1 Community



Height: 3.15 m

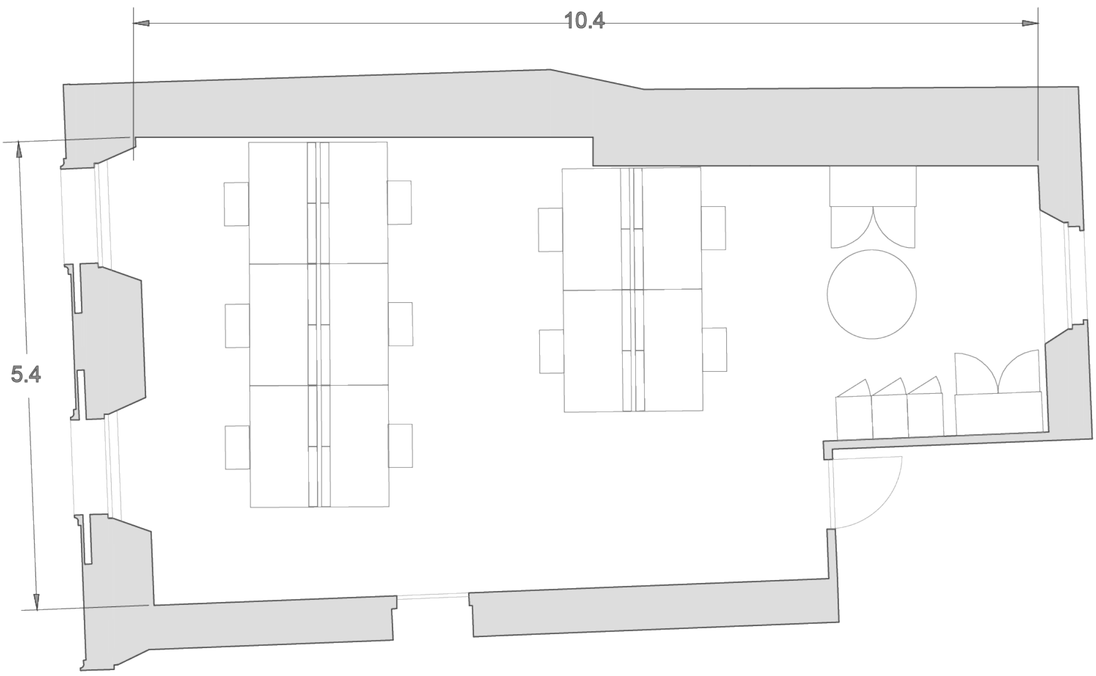
Area: 51.4 m^2

Volume: 161.9 m^3

Description:

The office consists of three solid masonry walls covered with plaster and one wall featuring large elevated glass windows, starting one meter above the floor and extending up to the ceiling. The flooring is made of plastic material, while the ceiling is a perforated acoustic drop ceiling with 20 cm of cavity space. Inside, there are three spacious wooden desks, providing a total of 18 workstations; there are no dividing elements between the workstations. Additionally, the office includes a large wooden cabinet along one of the longer sides.

05.2 Bench



Height: 3.55 m

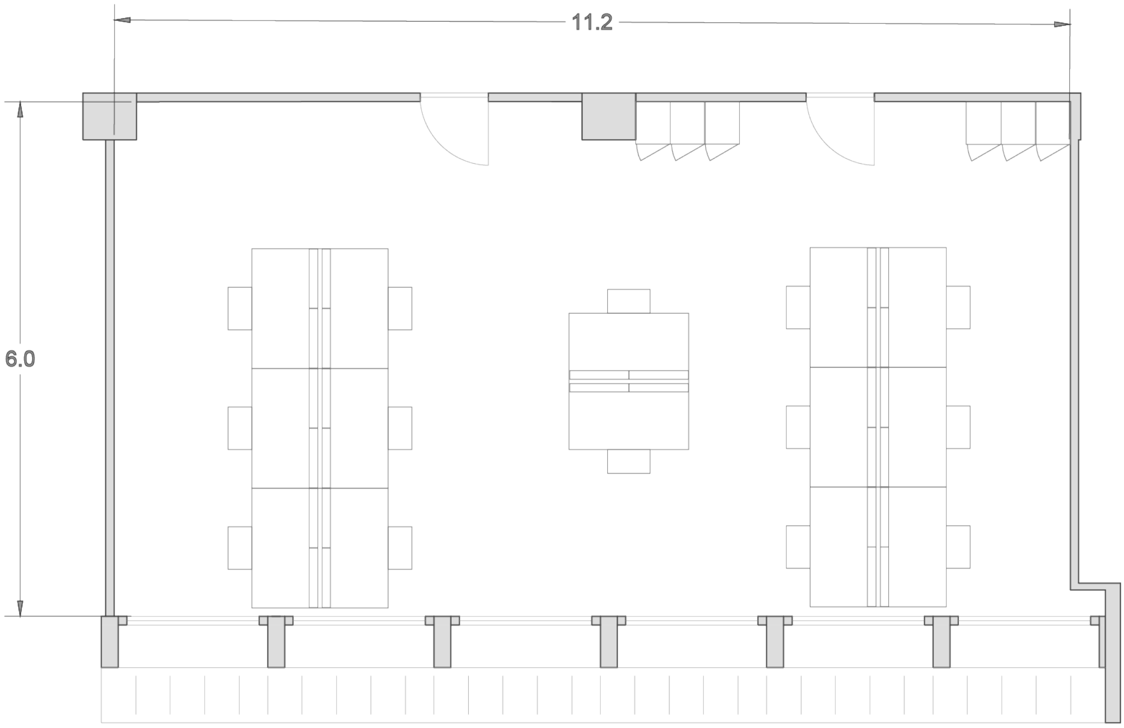
Area: 48.3 m^2

Volume: 171.5 m^3

Description:

The office has an irregular shape and is composed of a wider section housing two large desks and a narrower section where a small circular table is located; the narrower part also features small shelves. The shorter sides have elevated glass windows that start one meter above the floor and extend up to the ceiling. The flooring is wooden, while the plastered masonry walls enclose the space. The ceiling is of the acoustic drop ceiling type with perforated tiles and a 20 cm cavity space. The workstations are distributed across the two large tables, providing a total of ten seats. The spacious wooden desks have longitudinal dividers made of plastic material that are 40 cm high, serving as both visual and acoustic barriers.

05.3 Audit



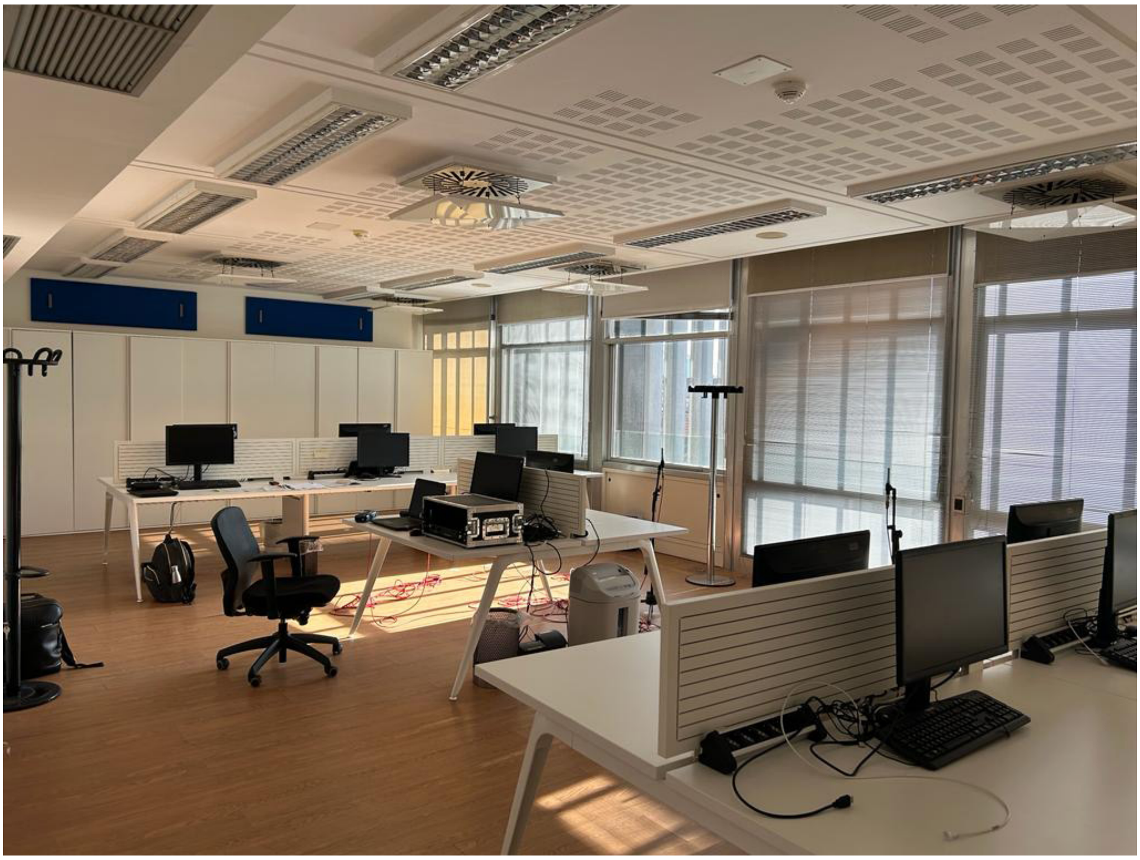
Height: 2.7 m

Area: 67.4 m^2

Volume: 181.9 m^3

Description:

The office has a regular shape with four sides; one of the long sides features a full-height glass wall, while the remaining walls are plastered masonry. There are two large desks and a smaller one positioned in the center of the room, providing a total of fourteen workstations. The wooden desks have longitudinal dividers that are 40 cm high, serving as visual and acoustic screens. The ceiling is of the acoustic drop ceiling type with perforated tiles and a 20 cm cavity space. On one of the shorter sides, there is a spacious wooden storage unit.



Measurements in the offices

06

06. Measurements in the offices

06.1 The BS EN ISO 3382-3:2022 Standard

The required instrumentation for the measurement procedures includes:

- Omnidirectional sound source
- Class 1 omnidirectional microphone
- Octave band spectrum analyzer
- Calibrator

Sound pressure level measurements must be carried out in an open-plan office regardless of its configuration, wall conditions (whether absorbent or not), internal partitions, and fixed or mobile furnishings. During measurements, the background noise level in a condition closest to the normal working hours should also be considered; therefore, ventilation systems must be operational at standard levels during measurements.

The standard defines acoustic measurement zones, which are areas of the office where wall treatment, ceiling height, and workstation configuration are similar. Within the same office, there can be multiple acoustic measurement zones, in which case measurements must be taken for each of these areas. Two measurement paths must be conducted for each acoustic measurement zone; when this is not possible, the standard suggests conducting measurements on a single path in both directions.

Particular attention should be given to the arrangement of microphones and the sound source. The standard specifies that microphone receivers, along with the sound source, should be positioned as linearly as possible, which means they should be placed on the same line. Figure 1 shows an example of a correct linear path in green and a non-linear path in red.

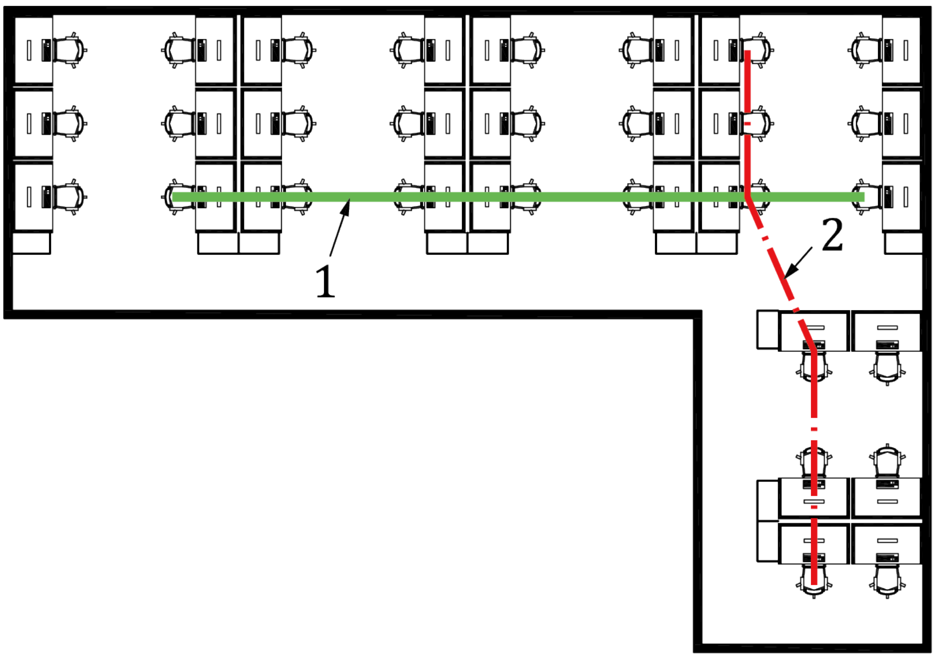


Figure 1 *Example of straight and a non straight measurement path in an open-plan office*

Once the path is defined, the sound source and measurement microphones are positioned. The sound source is placed at the end of the path, while the microphones are positioned at other points. The number of measurement points should be at least four, and the source point should also be included.

The position of the sound source, as well as the measurement microphones, should correspond to head height of a seated person. Therefore, the standard defines the height of the source and microphone as 1.2 m above the ground. The sound source should be at least 0.4 m away from the desk, and the distance from the midpoint of the source to the wall should always be greater than 1 m. The distance between microphones positioned along the measurement path should be at least 1 m. The power of the sound source should resemble the normal vocal effort of a person, and the signal should be pink noise containing all frequencies.

At each measurement point, the following measures should be determined:

- The distance ‘r’ between the midpoint of the source and the microphone
- The sound pressure level at the microphone produced by the source
- The sound pressure level of ambient noise
- The Speech Transmission Index (STI)

Subsequently, the standard specifies the formulas to calculate the values indicating the acoustic quality of the space. These values are:

- **rD**, distraction distance: the shortest distance from the midpoint of the omnidirectional sound source where the STI is lower than 0.5
- **D2,s**, spatial decay rate of speech: the rate of spatial decay of A-weighted sound pressure level of speech per distance doubling in decibels
- **Lp,A,S,4m**, speech level at 4m distance: the A-weighted sound pressure level

of speech in decibels at a distance of 4 m from the midpoint of the omnidirectional sound source

- **rc**, comfort distance: the shortest distance from the midpoint of the omnidirectional sound source where the A-weighted sound pressure level of speech is lower than 45 dB
- **Lp,A,B**, background noise level: the average and standard deviation of A-weighted sound pressure level of background noise over the measurement positions within the acoustic zone

The standard also provides reference values for these indices, defining intervals that define good and poor acoustic quality of spaces. The following values are listed:

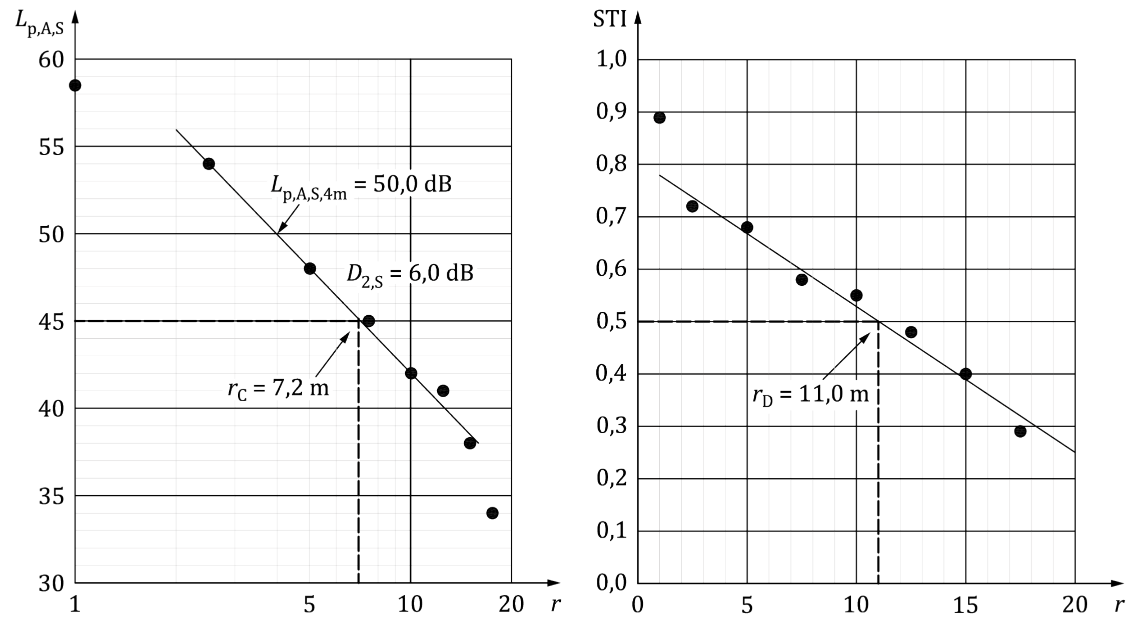
Typical single-number values indicating poor room acoustic conditions are

- rD > 11 m
- rC > 11 m
- D2,S < 5 dB
- Lp,A,S,4m > 52 dB
- Lp,A,B < 35 dB or Lp,A,B > 48 dB

Typical single-number values indicating good room acoustic conditions are

- rD < 5 m
- rC < 5 m
- D2,S > 8 dB
- Lp,A,S,4m < 48 dB
- Lp,A,B within 40 dB to 45 dB

Below are some examples of results taken from the standard and shown through graphs.



a) Determination of $D_{2,S}$, $L_{p,A,S,4m}$, and r_C. Linear fitting includes the positions within 2 m to 16 m from the OSS

b) Determination of r_D. Linear fitting includes all positions located beyond 1 m from the OSS

Key

$L_{p,A,S}$	overall A-weighted SPL of speech, dB	r_C	comfort distance, m
r	distance to the OSS, m	STI	speech transmission index
$D_{2,S}$	spatial decay rate of speech, dB	r_D	distraction distance, m
$L_{p,A,S,4m}$	A-weighted SPL of speech at 4,0 m, dB		

Figure 2 *Example of measurement results*

06.2 Measurements in Offices: Methods and Tools

The purpose of the measurements performed is to define acoustic parameters of a space to provide indicative values about its acoustic performance. The calculation method and measurement procedures are described in the BS EN ISO 3382-3:2022 standard, referring to the measurement method of acoustic parameters in an office without the presence of people.

The quality values derived from the measurements also consider background noise levels, while activities carried out within the office do not alter the measurement methodology or result calculations.

The instrumentation used for the measurements conducted at the Intesa San Paolo offices in Milan includes:

- Source: Brüel & Kjær OmniPower Sound Source Type 429[6], comprising 12 speakers arranged spherically to ensure omnidirectional radiation.
- Microphone: NTI Audio M2230, omnidirectional condenser microphone
- Acoustic Analyzer: NTI Audio XL2
- Power Amplifier: Lab Gruppen Lab 300
- Audio Interface: Tascam US-144 external USB interface
- Calibrator: Brüel & Kjær 4231

Measurements must be conducted in an open-plan office under any conditions of acoustic wall absorption, ceiling, and floor; the space must be furnished and equipped with partitions, whether fixed or movable. Background noise due to systems must be considered in measurements as it represents a sound level present during the normal use of the office.

The measurements taken at the Intesa San Paolo headquarters in Milan do not present different acoustic zones within each office. Therefore, measurements were taken individually for each office. Once the measurement position was identified, a measurement path was defined, i.e., the positions where the source and microphone positions should be within the room. This path should be as straight as possible, and if the environment is large enough, there should be two paths. In cases like the one described, measurements were taken in both directions along the same measurement path. The chosen measurement points should be at a height of 1.2 meters above the ground and correspond as closely as possible to the position of a seated worker's head. For these measurements, five points were chosen to form the measurement path. All measurements were taken with the source positioned at one vertex of the measurement path and the microphones positioned at the remaining four measurement positions. After these measurements were taken, the source was moved to the other vertex of the path, and measurements were taken at the other four measurement positions.

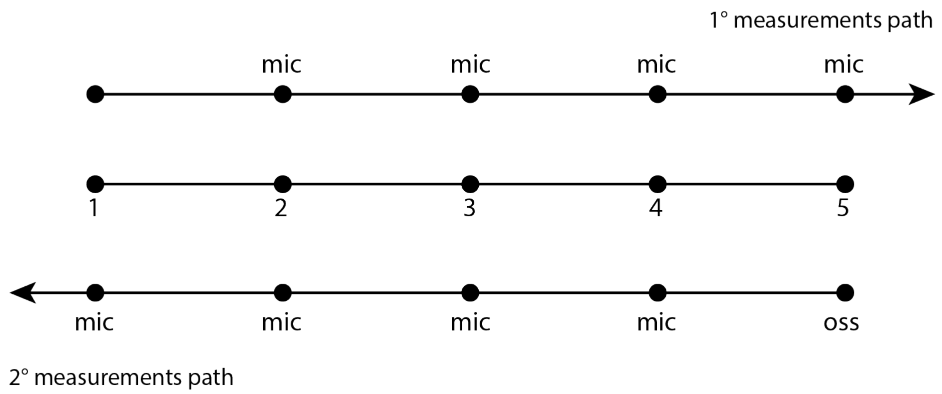


Figure 3 *Diagram placement of microphones and source in two different paths*

Once the microphone and source positions were defined, the following measurements were taken. First, the distances ‘r’ between the source and the chosen measurement positions were determined. Then, the sound pressure level at each position was measured for a signal containing all frequencies emitted by the source. The next measurement concerned the background noise level Lp,B, which was monitored for three minutes. Finally, the STI value was measured, which was directly provided by the sound level meter.

The standard provides limit values for the sound pressure level of the source. The source level should be at least 6 dB higher than the background noise level at the furthest measurement point and greater than the sound power level Lw,s corresponding to the average speech level. These values are provided in a table within the standard.

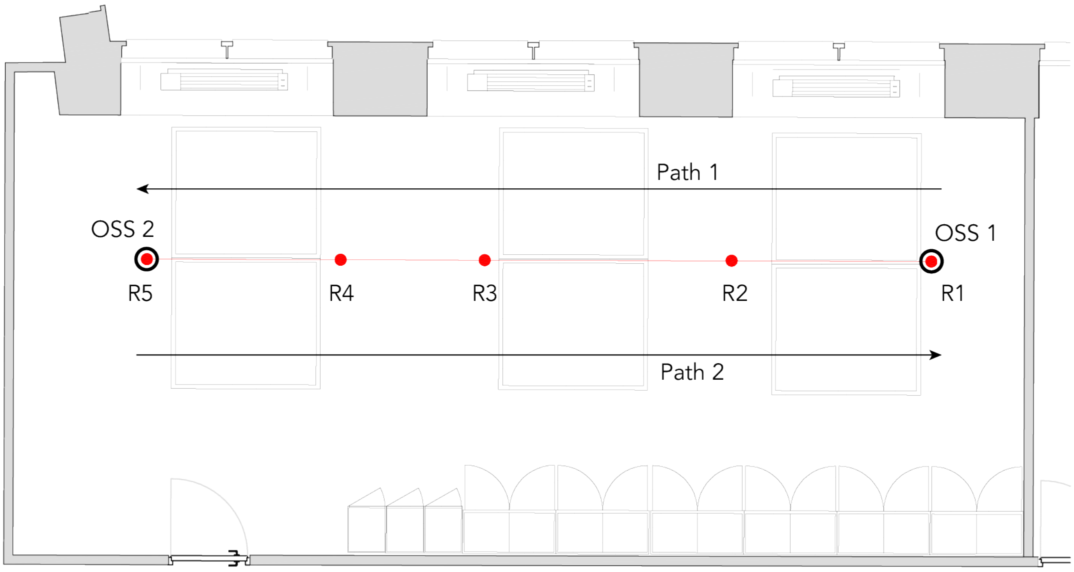
All measurements were recorded in octave bands from 125 Hz to 8000 Hz, and multiple iterations were performed to minimize potential errors. Once the data was acquired, it was sorted and used to calculate indicative numerical values of the acoustic quality of a space. The values required by the standard include: rd, defined as the distraction distance, which is the shortest distance from the source’s midpoint where the STI value is lower than 0.5; the spatial decay rate of speech D2,S, which is the amount of sound pressure level decay, in dBA, of speech with doubling of distance; another required value is the speech level at 4m distance Lp,A,S,4m, which is the A-weighted sound pressure level of speech at a distance of 4 meters from the source’s midpoint. The standard also provides for the calculation of the comfort distance rc, describing the shortest distance from the source’s midpoint where the A-weighted sound pressure level of speech is below 45 dB; the final value to calculate is the Lp,A,B value, which is the average and standard deviation of the A-weighted sound pressure level of background noise.

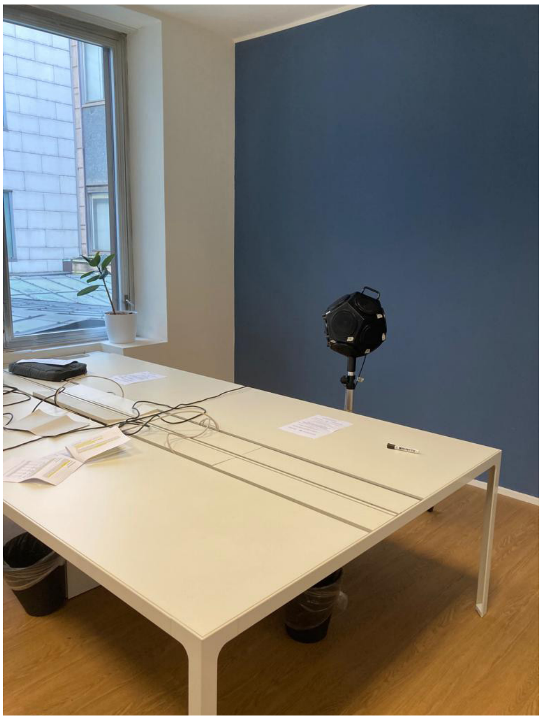
In addition to these values described in the standard, the reverberation time of the environment was also evaluated as an acoustic quality indicator. Specifically, the T30 value, which is the time in seconds that sound takes to decay by 30 dB, was considered. Reference values defining good or poor acoustic quality were taken from the French AFNOR NF S31-0802[2] standard, which defines optimal acoustic criteria for various environments, including offices. This standard defines the optimal T30 reverberation time for an open-plan office as efficient if less than 0.6 seconds and very efficient if less than 0.5 seconds.

In addition to the reverberation time, the STI value was also measured as a parameter to describe the acoustic quality of an open-plan office. The Speech Transmission Index (STI) ranges from 0 to 1 and indicates speech intelligibility; an STI value of 1 indicates complete speech intelligibility, while the closer the value is to 0, the fewer words are understood. Usually, a higher STI value is favorable for comprehension. However, in the case of open-plan offices where most of the disturbance comes from the speech of those occupying the same space, the STI value should be as low as possible. For this analysis, studies by Professor Valtteri Hongisto3 were considered, recommending an STI value of less than 0.5 for open-plan offices.

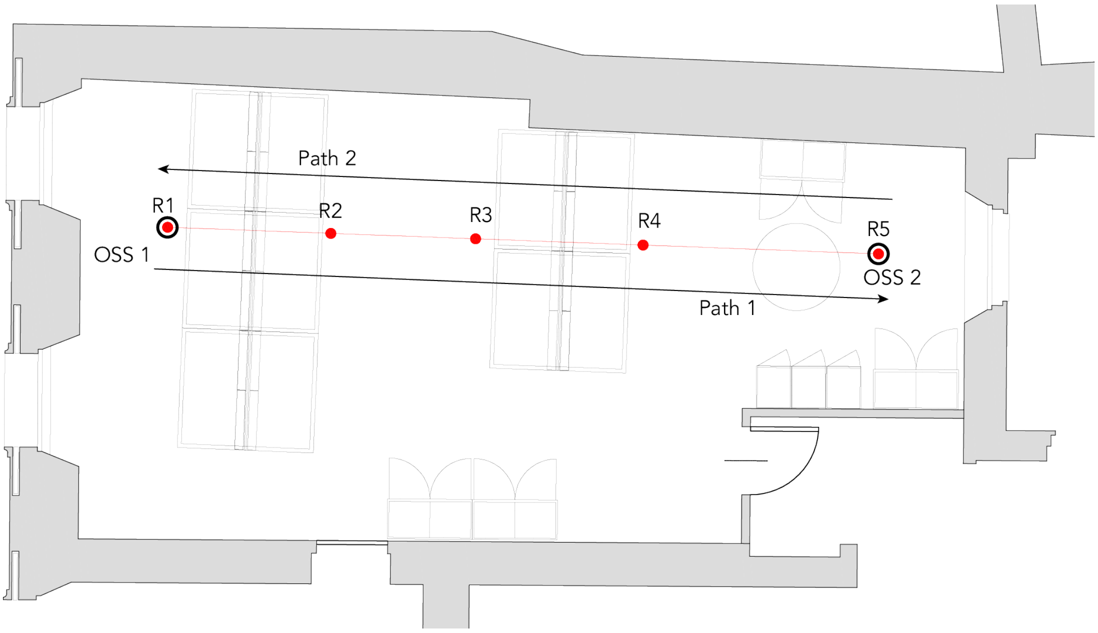
Below, the chosen microphone positions for each office are shown on the floor plan.

Community

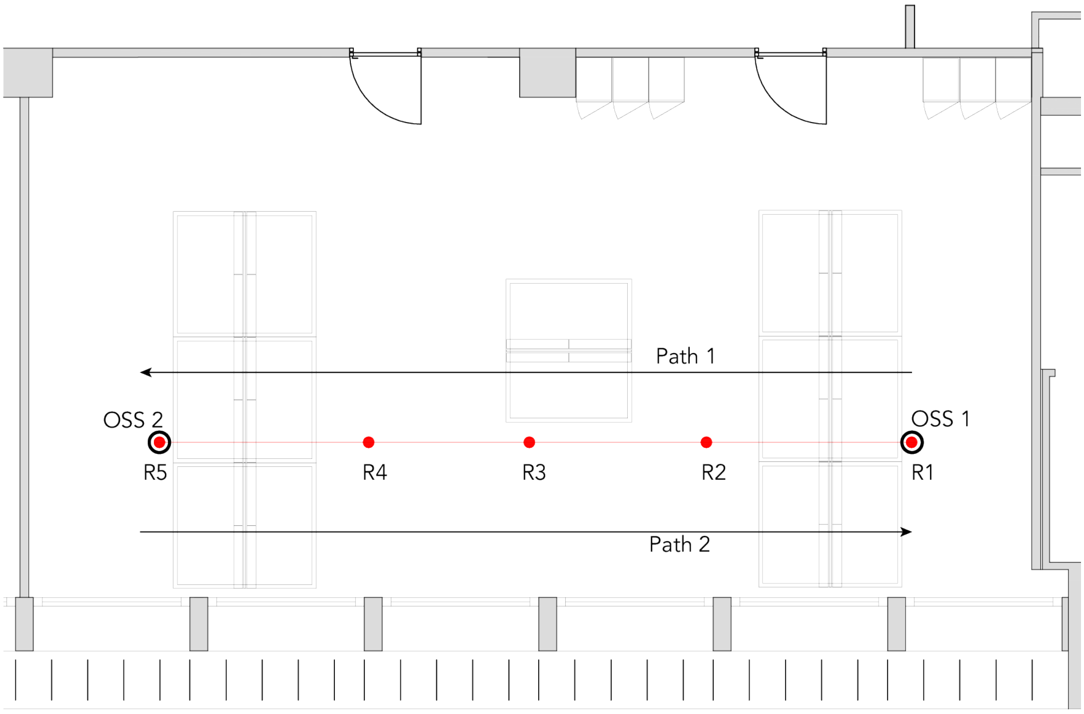


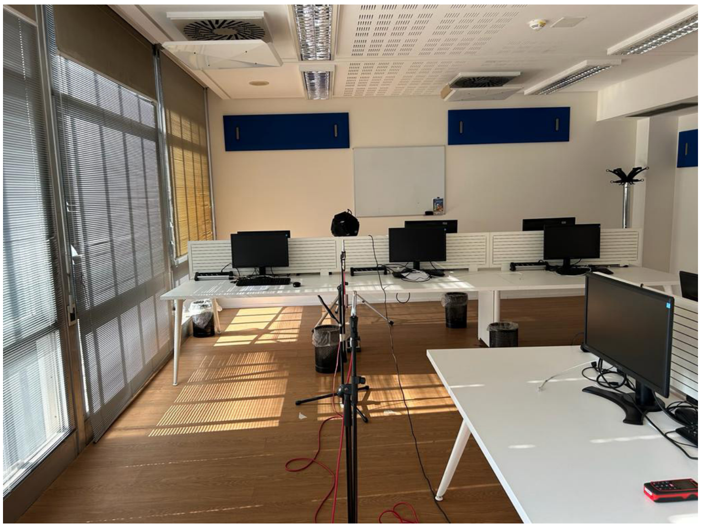


Bench



Audit





06.3 Results

The measurements were carried out in each office by three operators following the ISO 3382-3:2022 standard described earlier.The presented results encompass all parameters considered by the standard, along with the addition of two indices: T30 and STI.

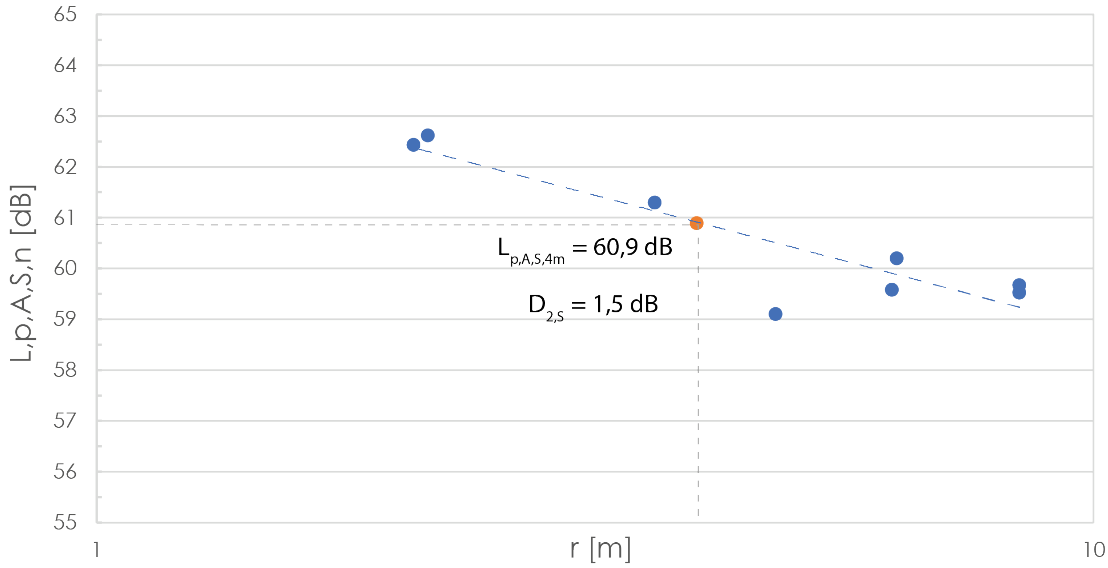
Lp,A,S,n

With this index, we indicate the variation of sound pressure level concerning distance. On the x-axis, distances in meters are indicated, while on the y-axis, sound pressure levels expressed in dB are shown. These graphs succinctly display how sound diminishes within the open-plan office as one moves away from the sound source. The slope of the interpolation line is quite significant and is represented by the D2,S index. A larger value of this index corresponds to a steeper slope, signifying a more pronounced sound decay as one moves away from the source. In an ideal open-plan office scenario, the decay, or slope of the line, should be as steep as possible to prevent sound from traveling long distances.

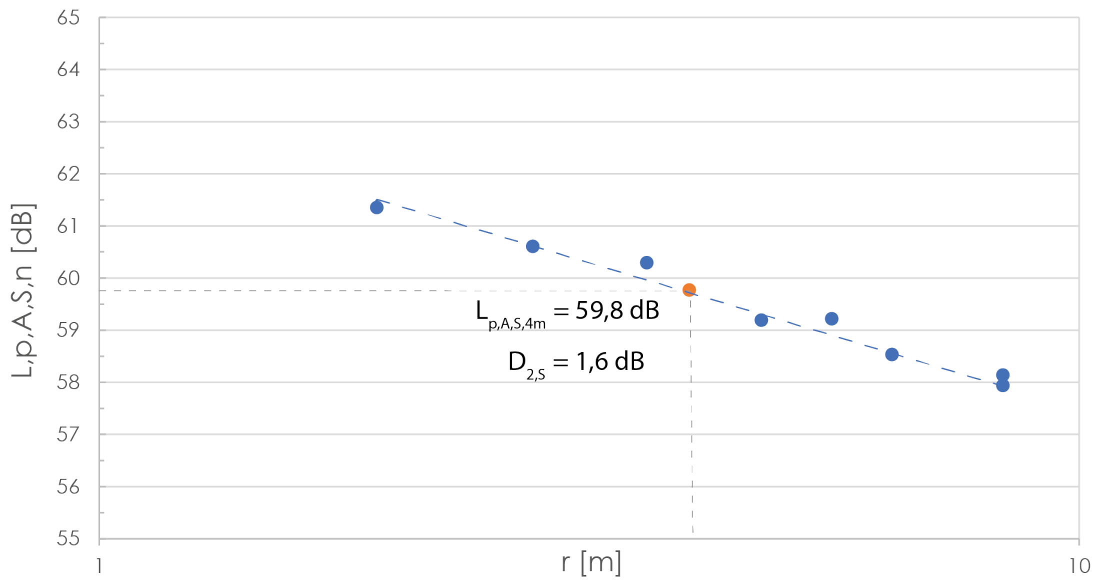
Another value required by the standard, Lp,A,S,4m, indicates the sound pressure level in dB at a specific point, 4 meters from the source. This point provides a comparable distance for assessment across different graphs. In this case as well, a lower sound pressure level at 4 meters signifies better acoustic quality of the environment, indicating rapid sound decay.

In the graph representing sound pressure levels, we also find the rc comfort distance value, indicating the distance from the source where the sound pressure level falls below 45 dB.

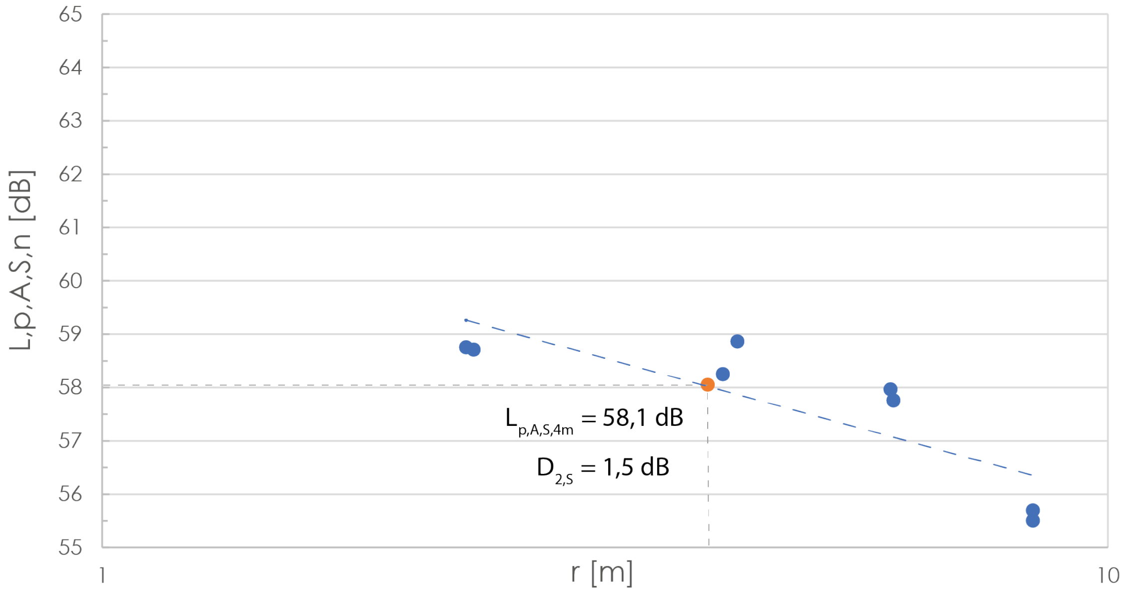
Community



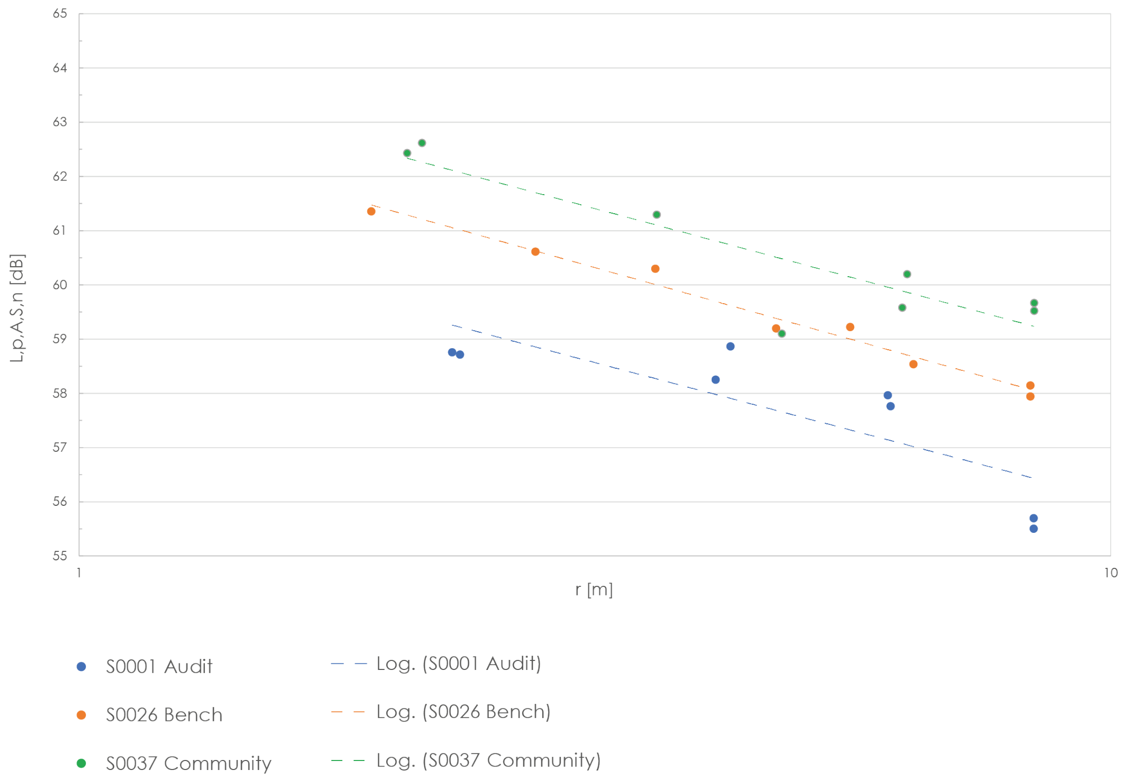
Bench



Audit



In this comparison table, it can be observed that the slope is minimal in all the offices, indicating a low level of sound decay as one moves away from the sound source.



STI

The STI, Speech Transmission Index, indicates the quality of signal transmission from the emitter to the receiver. This index varies from 0 to 1, where the maximum value represents complete intelligibility of the signal emitted by the speaker, while a low value indicates poor understanding of the emitted signal.

In the case of open-plan offices, as explained earlier, a low STI index is preferred since a high index would increase the perceived disturbance for the occupants of this workspace. Therefore, a high STI value promotes speech intelligibility, while a low value enhances speech privacy[6].

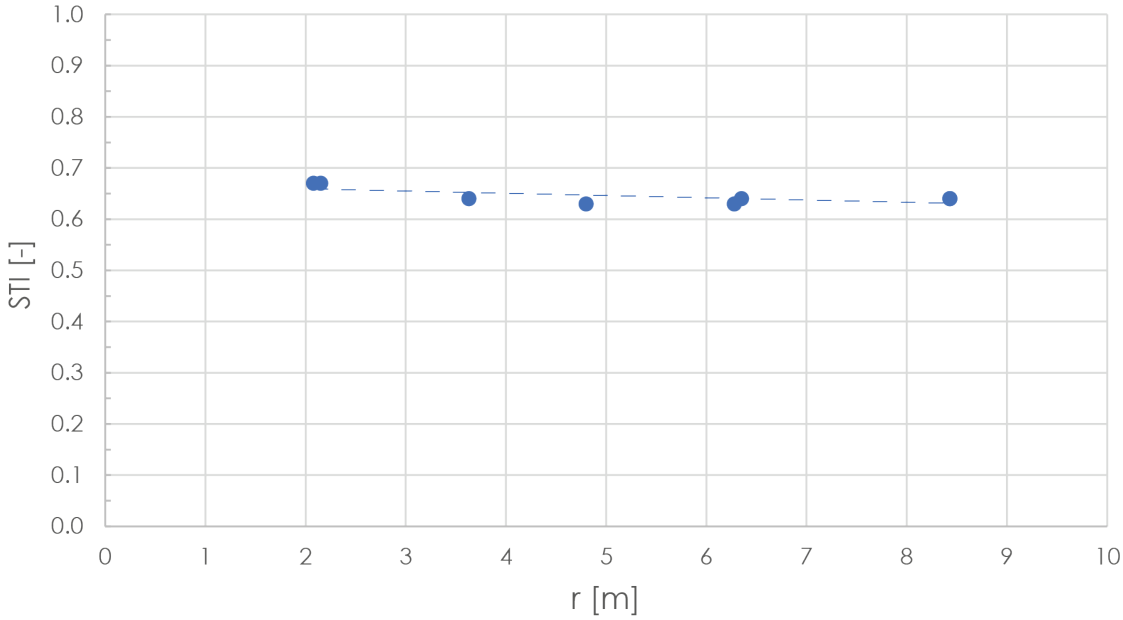
STI	Speech intellegibility	Speech privacy
0.00 - 0.05	*very bad*	*confidential*
0.05 - 0.20	*bad*	*bad*
0.20 - 0.40	*poor*	*reasonable*
0.40 - 0.60	*fair*	*poor*
0.60 - 0.75	*good*	*bad*
0.75 - 1.00	*excellent*	*very bad*

Figure 4 *Speech intellegibility and speech privacy*

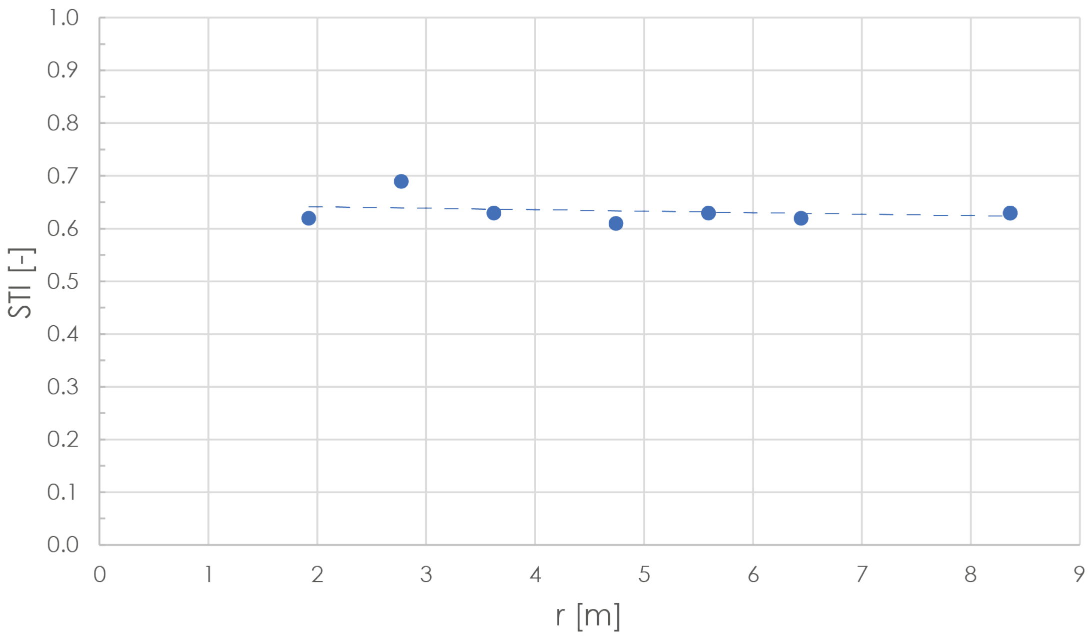
In the STI results graph, there is also another parameter, rD (distraction distance), which indicates the distance from the source where the STI falls below 0.5.

In the measurements conducted in the Milan offices, this value is not visible in the graphs since the STI never falls below 0.5.

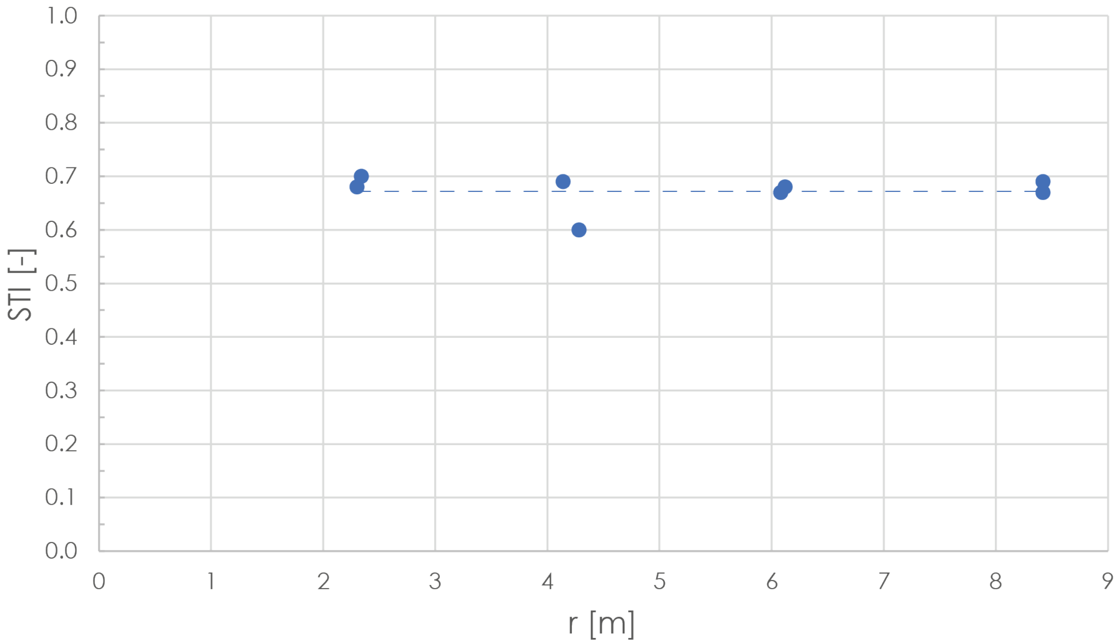
Community



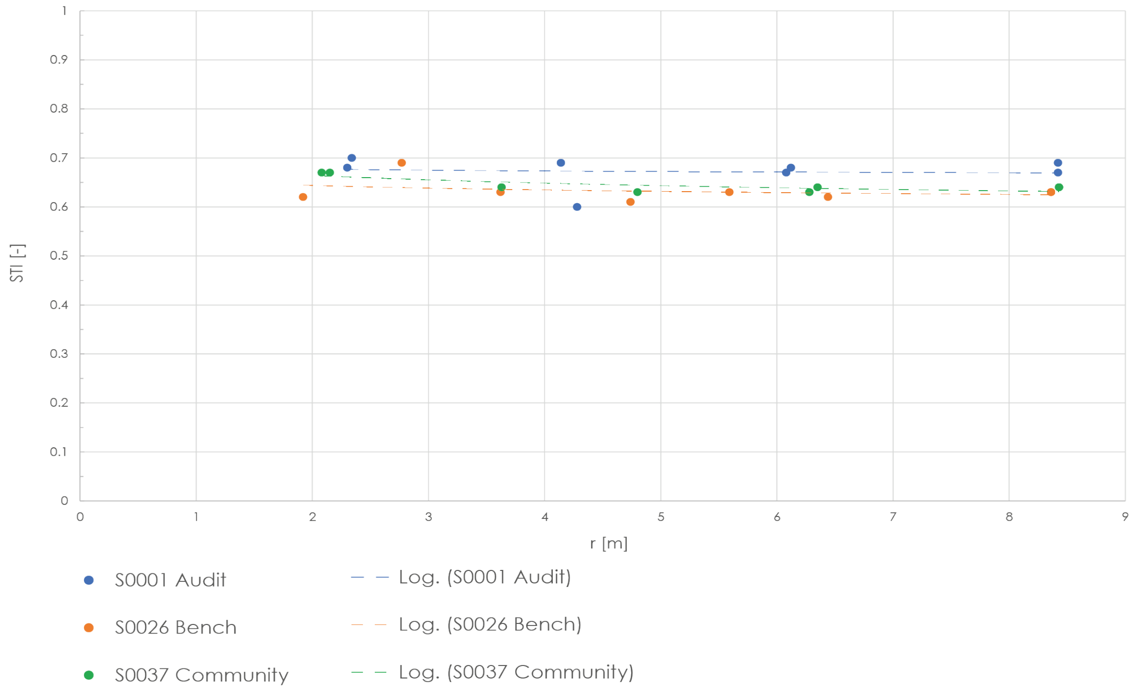
Bench



Audit



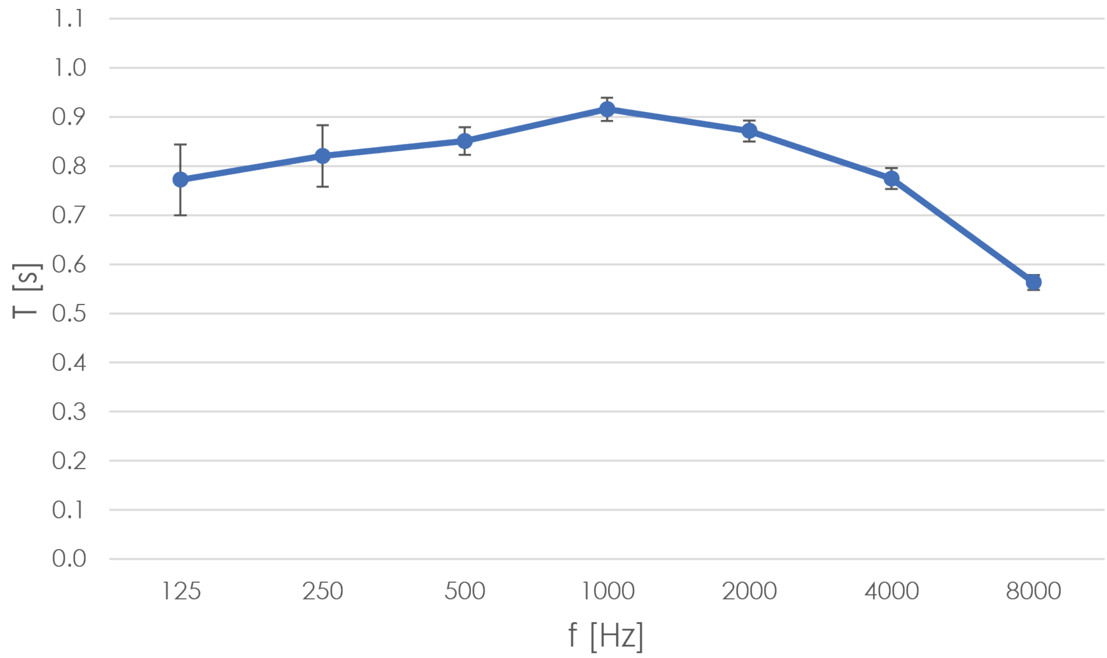
In this comparison table, it is clearly evident that the trend is consistent across the three offices; the STI values remain nearly the same as the distance varies, and in all cases, they are high values, above 0.5.



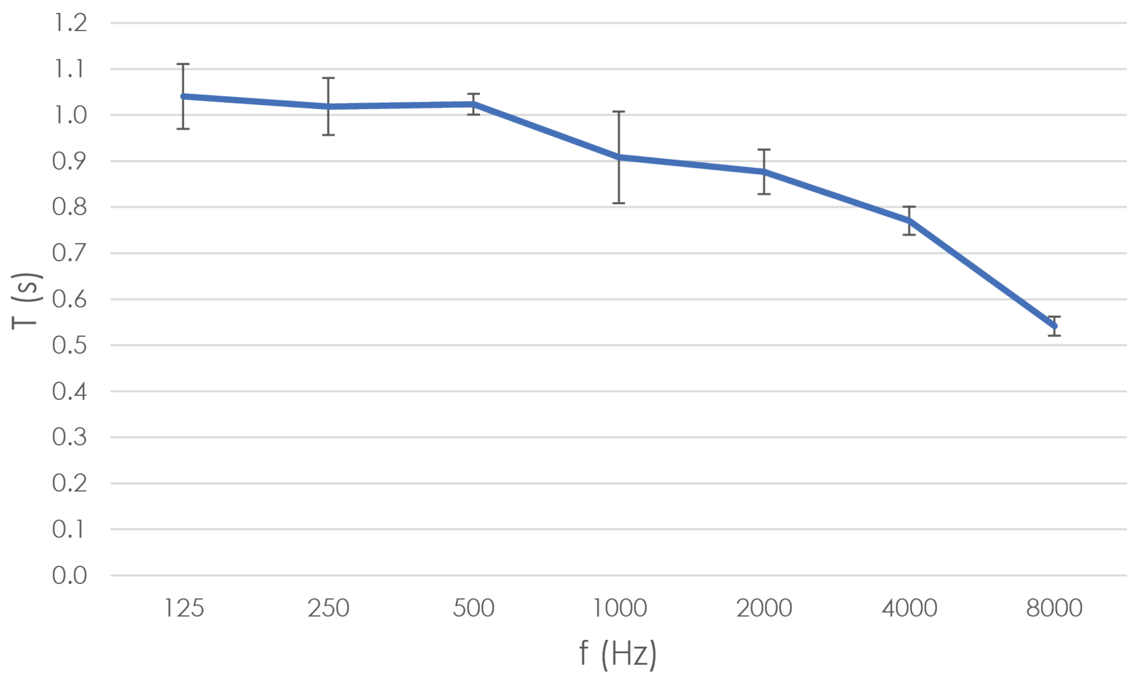
T30

Through this index, we aim to describe the behavior of the environment in relation to the acoustic absorption of its components. The reverberation time T30 indicates the time it takes for a signal to decay by 30 dB; this means that the more an environment has absorbing elements, the lower the T30 will be, as sound energy is largely absorbed. Conversely, an environment with reflective elements will tend to reflect sound energy, thereby increasing the reverberation time.

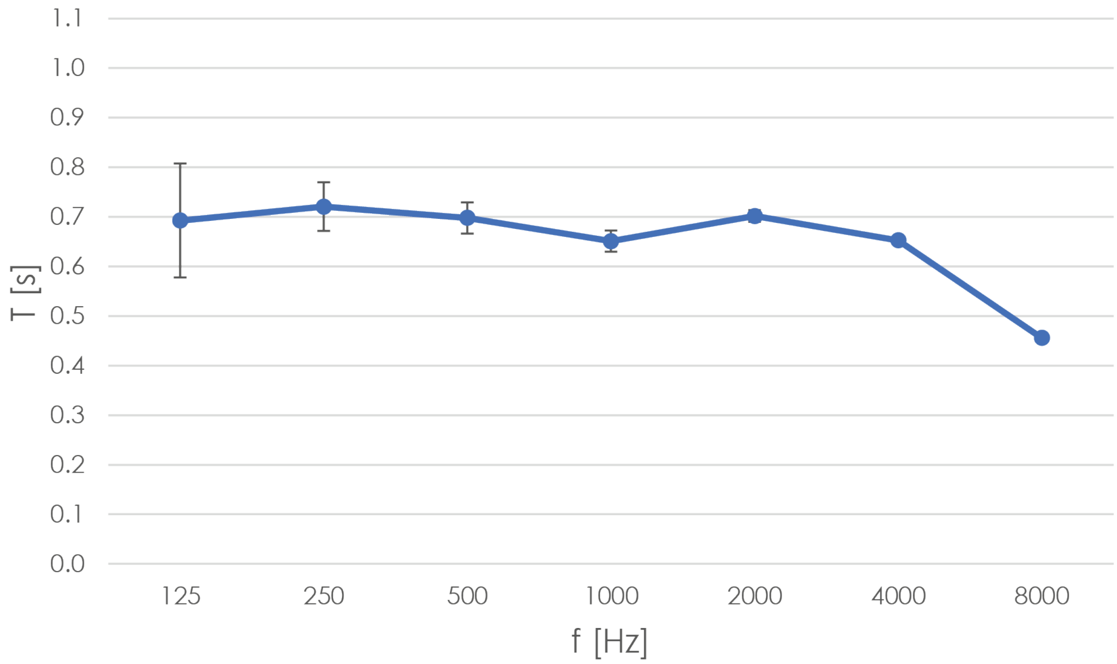
Community



Bench



Audit



Observing these graphs depicting the reverberation time by frequency, a trend in the shape of the curve is noticeable. Particularly, in reference to the French standard AFNOR NF S31-080, we note that the reverberation times are higher than the optimal values described; the French standard indicates a good average reverberation time of less than 0.6 seconds and excellent if less than 0.5 seconds.

Below is a summary table indicating all the considered indices and the values that denote good (green) or poor (red) acoustic quality.

Single values							
Description	**Unit**	**Quantities**	**Poor values**	**Good values**	**Community**	**Bench**	**Audit**
Distraction distance	m	r_d	>11	<5	-	-	-
Spatial decay rate of speech	dB	$D_{2,s}$	<5	>8	1.5	1.1	0.7
Speech level at 4 m distance	dB	$L_{p,A,S,4m}$	>52	<48	60.4	59.4	57.4
Comfort distance	m	r_c	>11	<5	>>11	>>11	>>11
Background noise level	dB	$L_{p,A,B}$	<35 o >48	40 ÷ 45	44.1	31.7	44.3
Reverberation time	s	$T30_{0.5\text{-}4kHz}$	>0.6	<0.5	0.85	0.89	0.68
Speech Trasmission Index	-	STI	>0.5	<0.5	0.65	0.63	0.67

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1. BS EN ISO 3382-3:2022. “Acoustics – Measurements of Room Acoustic Parameters, Part 3: Open Offices.”

2. AFNOR NF S31-080:2016. “Acoustic - Offices and Associated Areas Acoustic Performance Levels and Criteria by Type of Area.”

3. Hongisto, Valtteri, Annu Haapakangas, Johanna Varjo, Riikka Helenius, Hannu Koskela. “Refurbishment of an Open-Plan Office - Environmental and Job Satisfaction.” Journal of Environmental Psychology, 2016. doi: 10.1016/j.jenvp.2015.12.004.

4. Aram Seddigh, Erik Berntson, Fredrik Jönsson, Christina Bodin Danielson, Hugo Westerlund. “The Effect of Noise Absorption Variation in Open-Plan Offices: A Field Study with a Cross-Over Design.” Journal of Environmental Psychology, Volume 44, 2015, Pages 34-44.

5. Haapakangas, Annu, Valtteri Hongisto, Jukka Hyönä, Joonas Kokko, Jukka Keränen. “Effects of Unattended Speech on Performance and Subjective Distraction: The Role of Acoustic Design in Open-Plan Offices.” Applied Acoustics, 2014, 86, 1–16. doi: 10.1016/j.apacoust.2014.04.018.

6. Hilge C. and Noche C. “Office Acoustics.” Buero-forum, 2001.

Calibration

07

07. Calibration

07.1 Odeon

Odeon is software used for the acoustic simulation of environments; it allows obtaining acoustic parameters of a space through computerized simulation. This software employs the image-source method combined with a ray-tracing algorithm. Odeon analyzes sound energy as if it were composed of rays originating from the source and dispersing in the environment by reflecting off surfaces. By utilizing a large number of rays and managing reflection on each surface, the software generates a realistic simulation of room behavior.

The simulation occurs in three main steps:

- Model Creation
- Source and Receiver Selection
- Material Selection

The initial step involves creating a 3D model of the space to be measured; in my case, SketchUp software was chosen to create the office model. Subsequently, the 3D model is converted through a plugin into Odeon's proprietary format to be imported and opened in the simulation software. The model must be greatly simplified, as modeling complex geometries could complicate calculations and yield inaccurate results.

Once the model is imported into the software, it's necessary to select the positions of sound sources and receivers. Odeon allows choosing from various source types, adjusting their power levels, and importing source models not present in the system. The microphone selection is also extensive, varying from operating model to polar pattern.

Before conducting the calculation simulation, it's required to assign a material to each surface. In the materials section, a list of all geometric surfaces comprising the model is available; for each, one can choose the material and scattering coefficient, which determines how reflection occurs on that specific surface—whether more geometric or random in nature. Each surface will have its specific material and absorption coefficient, making ray behavior more realistic whenever they impact a surface.

With all these parameters set, it’s possible to conduct the simulation calculation and obtain all the acoustic parameters for that specific environment.

In Figure 1, an example of ray tracing in a simple environment is visible.

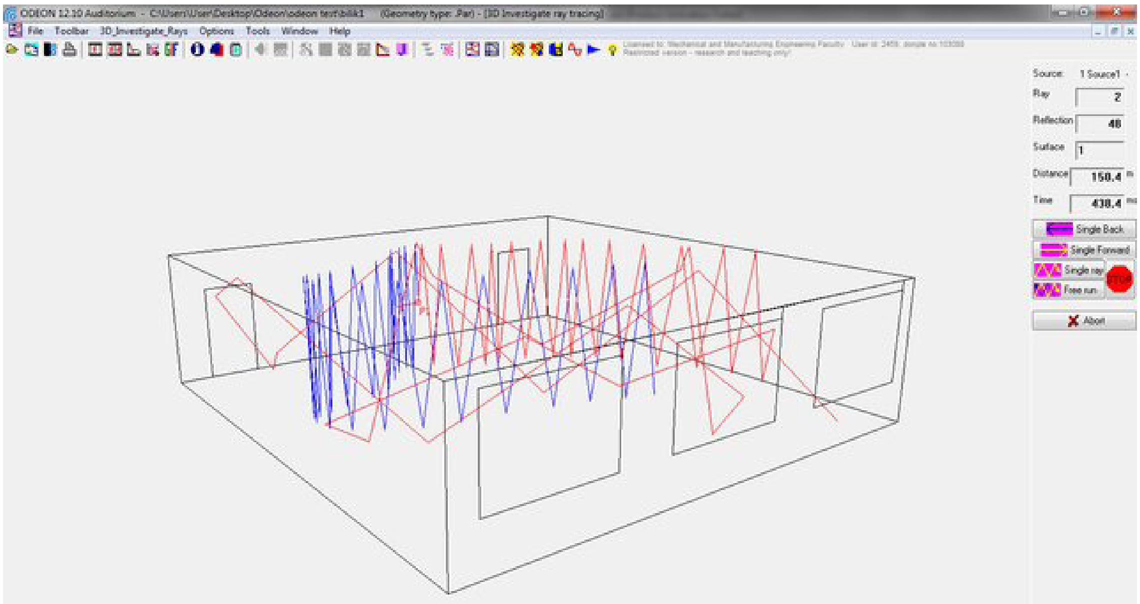


Figure 1 *3d model on Odeon*

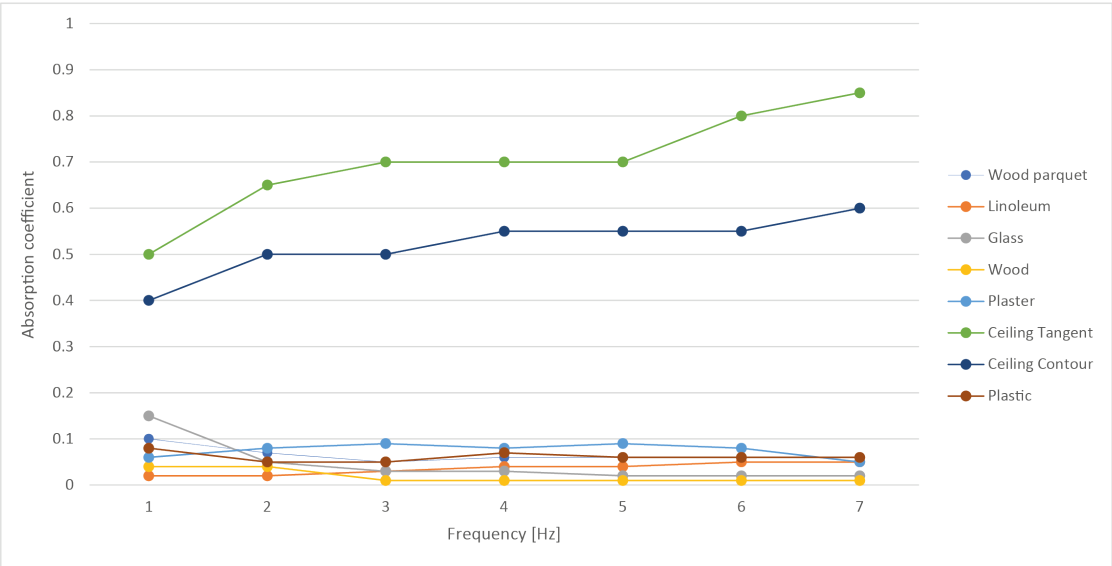
07.2 The 3D Model

Calibrating the model is a crucial step in designing an existing environment. The aim is to create a digital environment that behaves as faithfully as possible to the real environment. In this case, all three offices of Intesa San Paolo in Milan were modeled, and for the purpose of acoustic improvement, the starting models must possess the same characteristics as the original offices. This implies that the simulated model and the real environment must have the same measured acoustic parameters. Once the simulated environment “sounds” like the real one, a realistic basis is established for the improvement project. This approach anticipates that the results obtained from the simulated acoustic project will align with the measurements made in the newly designed environment.

Calibrating a model primarily occurs through material selection and, consequently, their absorption coefficient. In an ideal scenario, if we insert the correct materials into our model, the simulation results should match those of the real environment, as the geometries and materials are the same. However, in actual projects, this isn’t always the case since material coefficients are not always the same as those of real materials in the environment, and geometries are simplified. Thus, calibration is an iterative process where different materials are used to achieve a simulated outcome as faithful as possible to field measurements.

Below is a table depicting the materials used for calibration and their absorption coefficients.

Materials	Frequency						
	125	250	500	1000	2000	4000	8000
floor (wood parquet)	0.10	0.07	0.05	0.06	0.06	0.06	0.06
floor (linoleum)	0.02	0.02	0.03	0.04	0.04	0.05	0.05
window (glass)	0.15	0.05	0.03	0.03	0.02	0.02	0.02
desk (wood)	0.04	0.04	0.01	0.01	0.01	0.01	0.01
door (wood)	0.04	0.04	0.01	0.01	0.01	0.01	0.01
furniture (wood)	0.04	0.04	0.01	0.01	0.01	0.01	0.01
wall (plaster)	0.06	0.08	0.09	0.08	0.09	0.08	0.05
ceiling Knauf Danoline Tangent T1 200mm	0.50	0.65	0.70	0.70	0.70	0.80	0.85
ceiling Knauf Danoline Contour micro	0.40	0.50	0.50	0.55	0.55	0.55	0.60
desk screen (plastic)	0.08	0.05	0.05	0.07	0.06	0.06	0.06



07.3 Results

Below are the calibration results for the three offices at Intesa San Paolo in Milan.

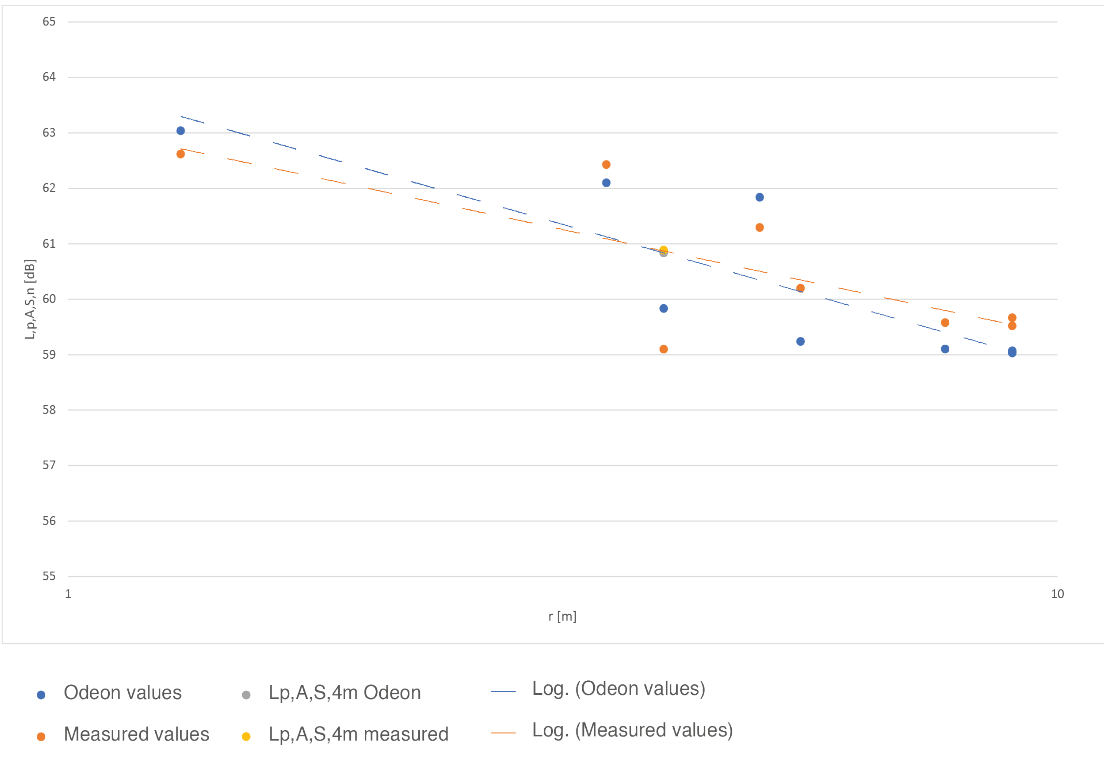
The values considered for calibration encompass all descriptors specified by ISO 3382-3:2022, complemented by reverberation time and STI values.

For results describing sound pressure levels, a value within a 1 dB delta from the measured value is considered valid. Conversely, for reverberation time, the curve resulting from the simulation should remain within a 5% delta, either higher or lower, compared to the measured curve within the offices.

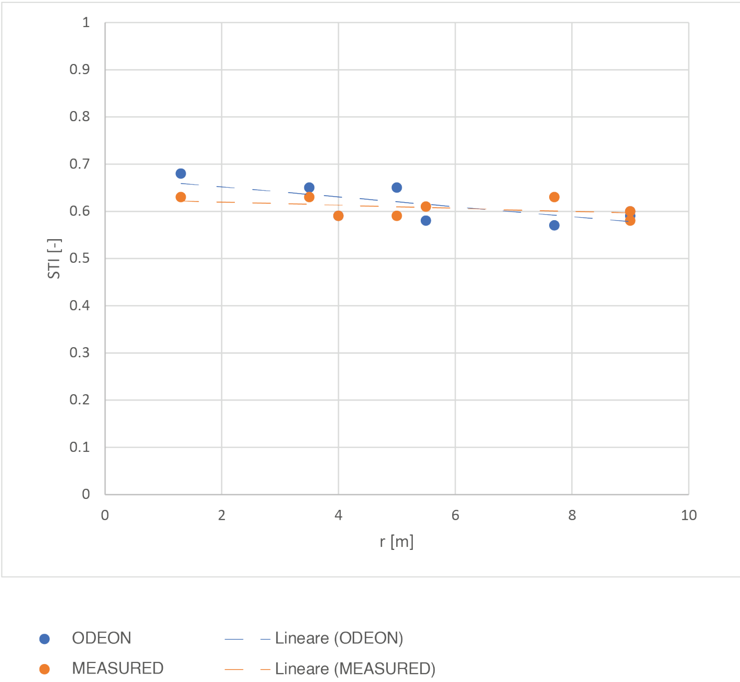
Community

S0037 COMMUNITY					
Quantity	Units	Poor values	Good values	Simulation	Measured
rd	m	>11	<5	-	-
D2,s	dB	<5	>8	1.52	1.50
Lp,A,S,4m	dB	>52	<48	60.84	60.90
rc	m	>11	<5	>>11	>>11
Lp,A,B	dB	<35 o >48	40 ÷ 45	44.08	44.10
T30 0.5-4kHz	s	> 0.5	< 0.5	0.87	0.85

Sound pressure level

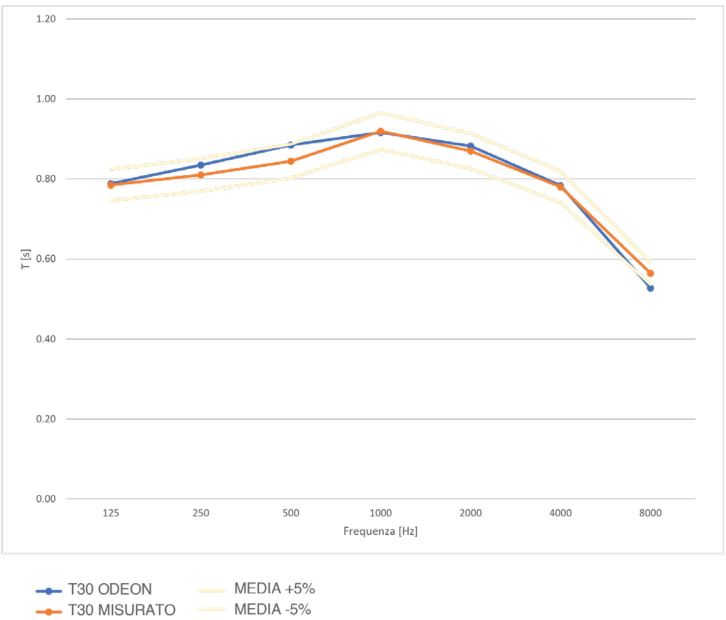


STI



1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
STI [-]
0
2
4
6
8
10
r [m]
ODEON
MEASURED
Lineare (ODEON)
Lineare (MEASURED)

T30

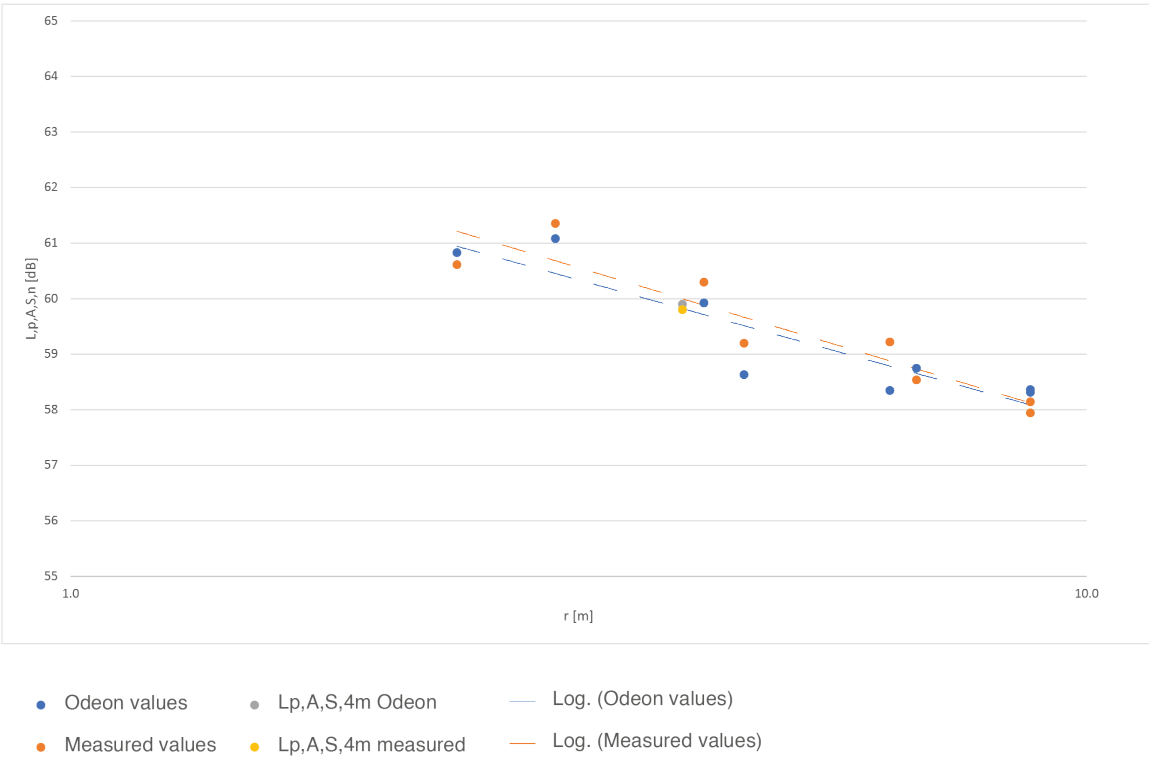


1.20
1.00
0.80
0.60
0.40
0.20
0.00
T [s]
125
250
500
1000
2000
4000
8000
Frequenza [Hz]
T30 ODEON
T30 MISURATO
MEDIA +5%
MEDIA -5%

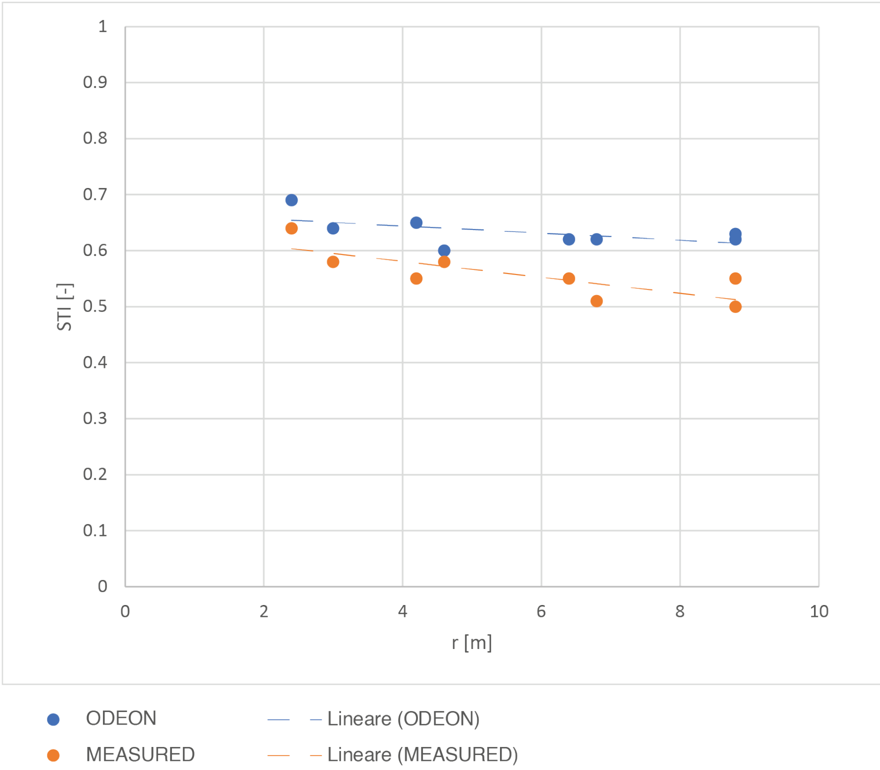
Bench

S0026 BENCH					
Quantity	Units	Poor values	Good values	Simulation	Measured
rd	m	>11	<5	-	-
D2,s	dB	<5	>8	1.52	1.60
Lp,A,S,4m	dB	>52	<48	59.80	59.80
rc	m	>11	<5	>>11	>>11
Lp,A,B	dB	<35 o >48	40 ÷ 45	31.65	31.70
T30 0.5-4kHz	s	> 0.5	< 0.5	0.88	0.89

Sound pressure level



STI



STI [-]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
r [m]
ODEON
MEASURED
Lineare (ODEON)
Lineare (MEASURED)

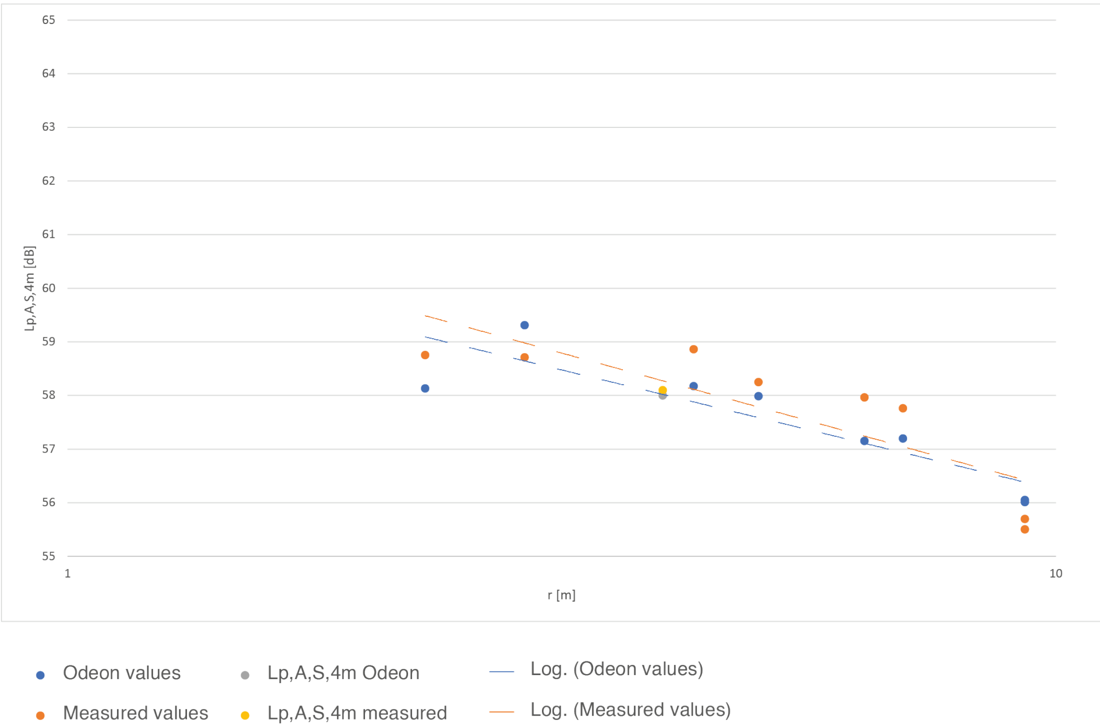
T30

T [s]
1.20
1.00
0.80
0.60
0.40
0.20
0.00
125
250
500
1000
2000
4000
8000
Frequenza [Hz]
T30 ODEON
T30 MISURATO
MEDIA +5%
MEDIA -5%

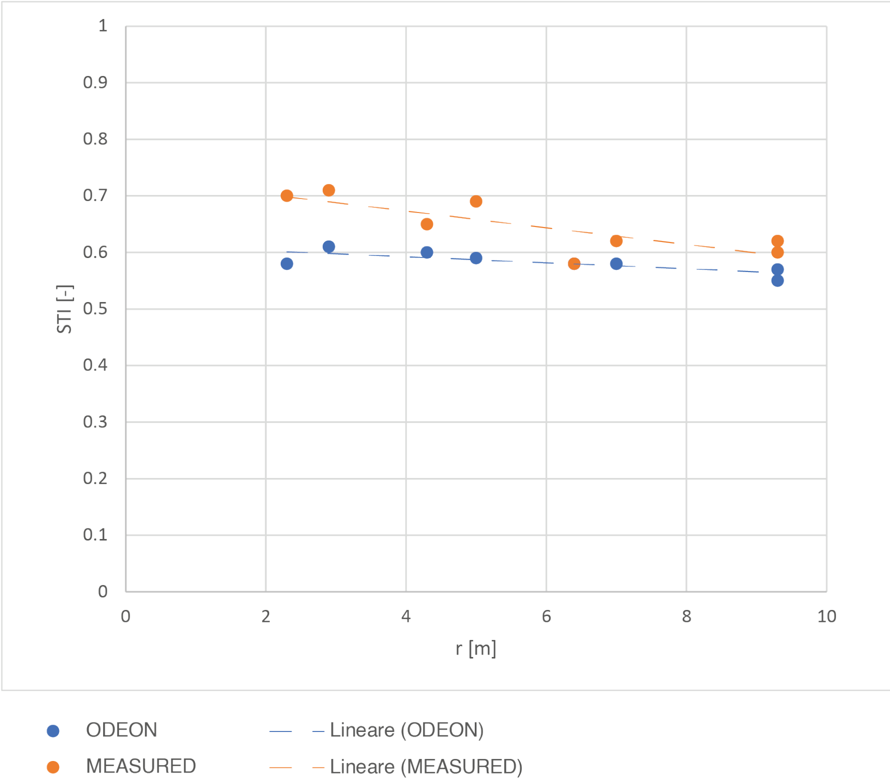
Audit

S0001 AUDIT					
Quantity	Units	Poor values	Good values	Simulation	Measured
rd	m	>11	<5	-	-
D2,s	dB	<5	>8	1.34	1.50
Lp,A,S,4m	dB	>52	<48	58.00	58.05
rc	m	>11	<5	>>11	>>11
Lp,A,B	dB	<35 o >48	40 ÷ 45	44.30	44.30
T30 0.5-4kHz	s	> 0.5	< 0.5	0.67	0.67

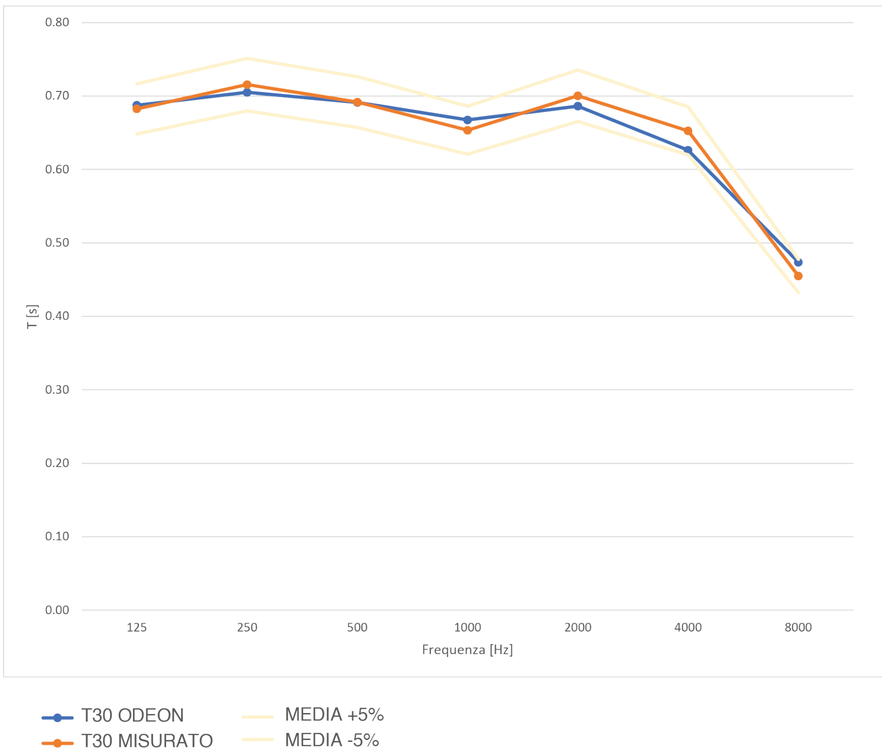
Sound pressure level



STI


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
STI [-]
0
2
4
6
8
10
r [m]
ODEON
MEASURED
Lineare (ODEON)
Lineare (MEASURED)

T30


0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
T [s]
125
250
500
1000
2000
4000
8000
Frequenza [Hz]
T30 ODEON
T30 MISURATO
MEDIA +5%
MEDIA -5%

The acoustic project

08

08. Project

08.1 The Matrix

The acoustic correction project involves the incorporation of new elements such as suspended ceilings, panels, baffles, and acoustic furnishings to enhance the acoustic conditions of the office according to the parameters outlined in ISO 3382-3:2022.

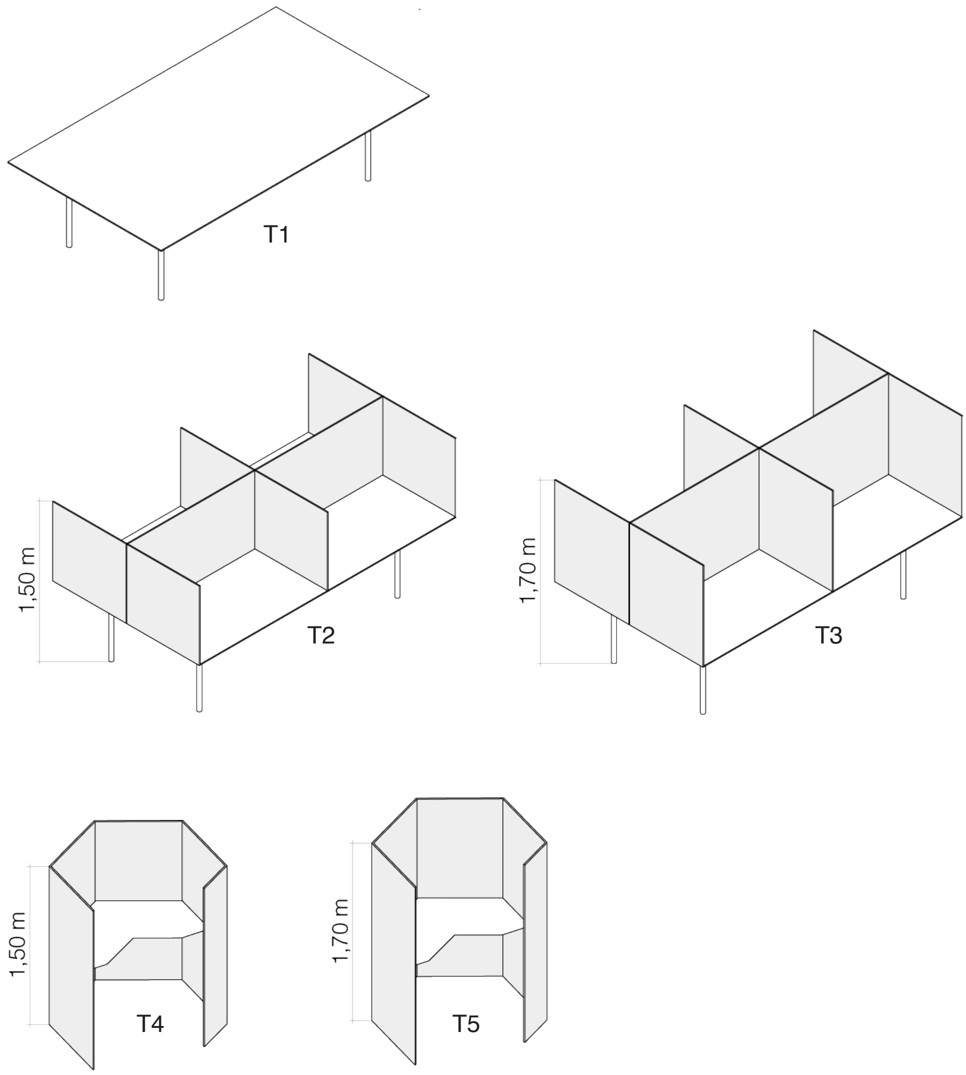
Before making decisions about which elements to use, a preliminary study was conducted to analyze the acoustic behavior of the elements when combined. This approach provides insights into the best choices for the actual office design based on the achieved results.

The outcomes will demonstrate how certain objects, such as baffles, perform better compared to using only acoustic suspended ceilings. Moreover, the simulations will reveal which parameter is better suited for specific elements in comparison to others. This is because an object we introduce, like wall-absorbing panels, could improve the reverberation time value but might adversely affect the STI value. By using this matrix of simulated results, we can make informed decisions about which elements to utilize for the design of the Community office.

The tested elements can be categorized into three groups: the first category, denoted by the letter T, concerns screens that partition workstations; the second category, denoted by the letter C, pertains to ceiling elements; while the third category, denoted by the letter W, addresses wall surface treatment.

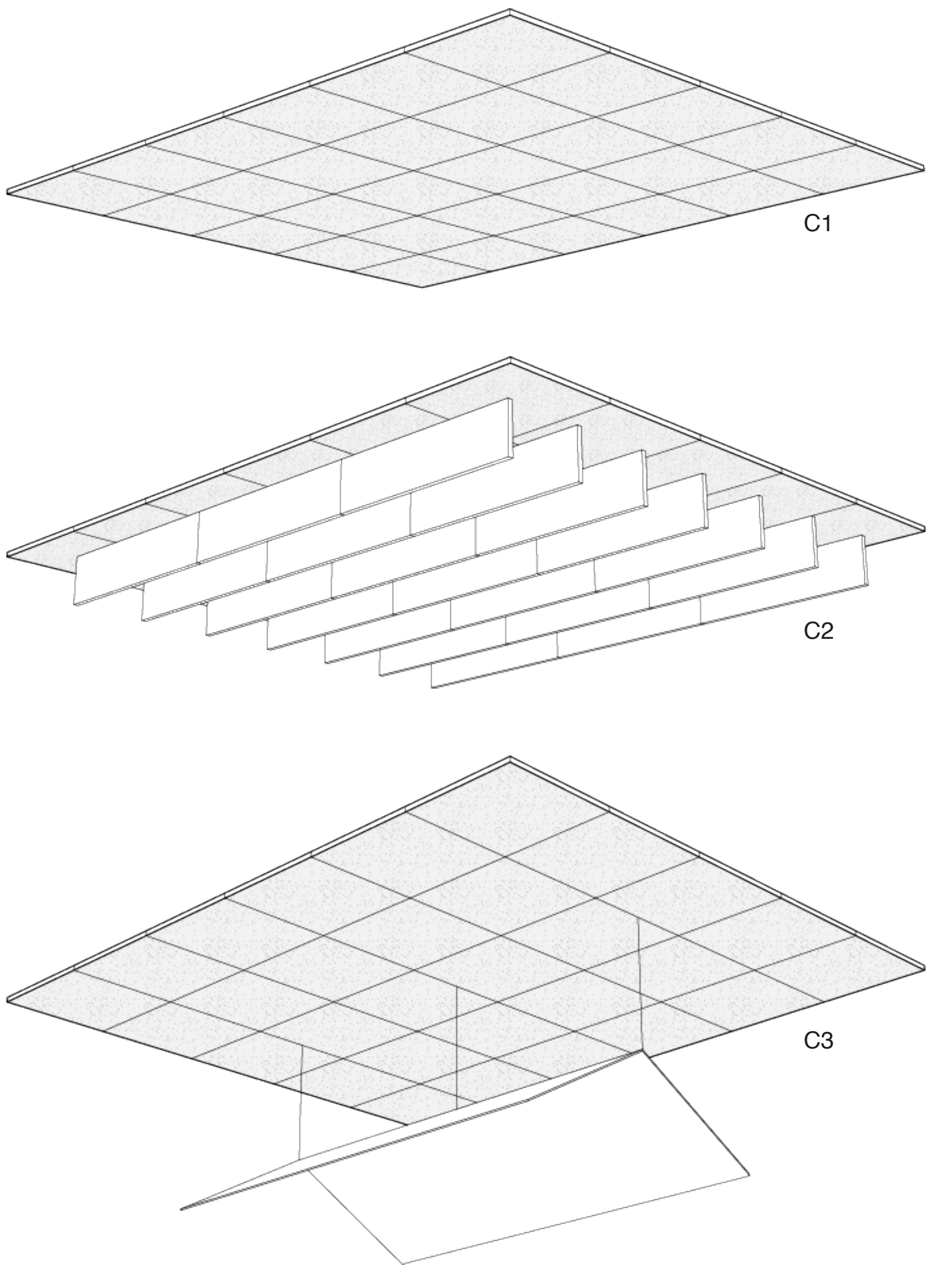
Regarding category T, screens, five potential configurations were selected:

- T1: Involves using desks without any acoustic screens.
- T2: Involves using acoustic screens between desks at a height of 1.5 meters from the floor.
- T3: Involves using acoustic screens between desks at a height of 1.7 meters from the floor.
- T4: Involves using closed cubicles on three sides at a height of 1.5 meters from the floor.
- T5: Involves using closed cubicles on three sides at a height of 1.5 meters from the floor.



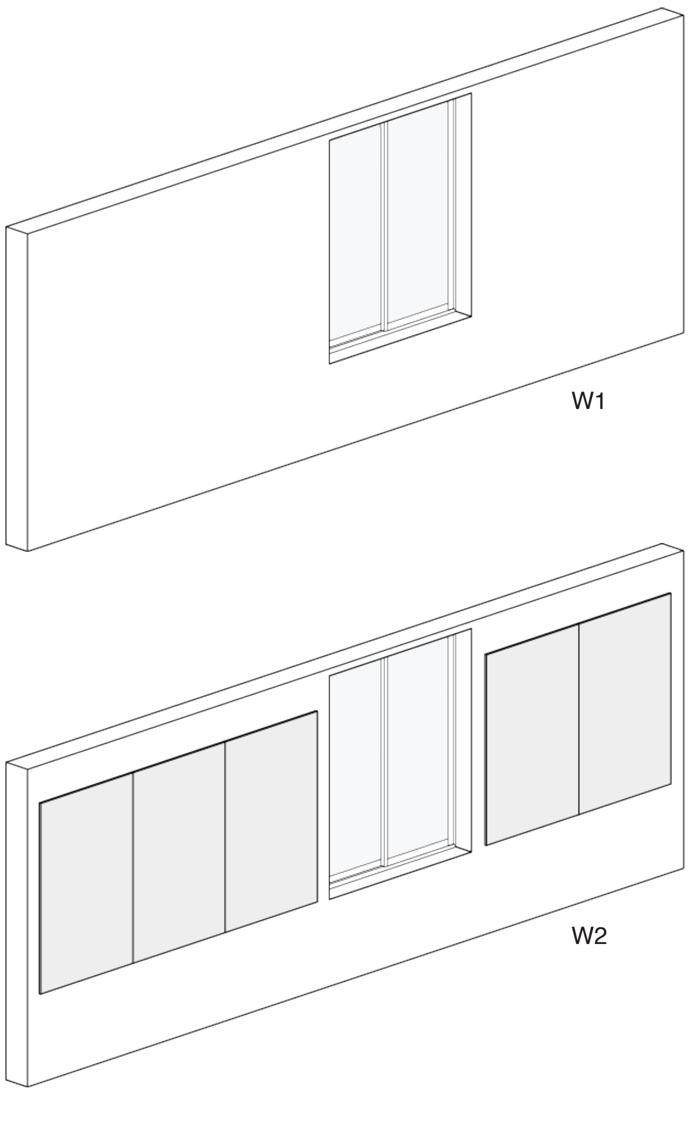
Category C, which addresses ceiling acoustic treatment, has three configurations:

- C1: Involves installing an acoustic suspended ceiling.
- C2: Involves incorporating baffles onto the acoustic suspended ceiling.
- C3: Involves installing a suspended acoustic covering element attached to the acoustic suspended ceiling.



Category W, concerning wall acoustic treatment, comprises two configurations:

- W1: Does not involve installing wall-mounted acoustic panels.
- W2: Involves installing wall-mounted acoustic panels.



Tables 1 and 2 respectively illustrate a legend of configurations and the matrix resulting from combining all the elements.

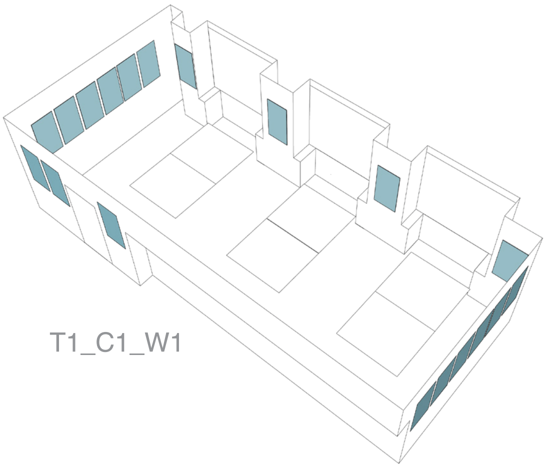
Legend	
T1	Desk without acoustic screen
T2	Desk with front and lateral acoustic screen of height 1.5m
T3	Desk with front and lateral acoustic screen of height 1.7m
T4	Cubicles with 1.5m acoustic screen
T5	Cubicles with 1.7m acoustic screen
C1	Acoustic ceiling
C2	Acoustic ceiling with baffle
C3	Acoustic ceiling with acoustic suspended cover element
W1	Wall with acoustic panels
W2	Wall without acoustic panels

Table 1 *Legend of configuration*

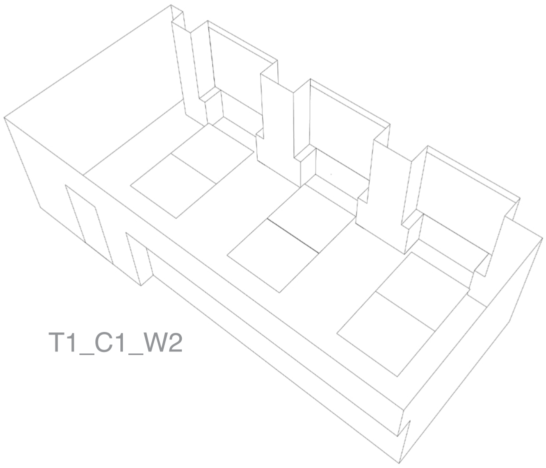
Configurations										
	T1		T2		T3		T4		T5	
C1	T1_C1_W1	T1_C1_W2	T2_C1_W1	T2_C1_W2	T3_C1_W1	T3_C1_W2	T4_C1_W1	T4_C1_W2	T5_C1_W1	T5_C1_W2
C2	T1_C2_W1	T1_C2_W2	T2_C2_W1	T2_C2_W2	T3_C2_W1	T3_C2_W2	T4_C2_W1	T4_C2_W2	T5_C2_W1	T5_C2_W2
C3	T1_C3_W1	T1_C3_W2	T2_C3_W1	T2_C3_W2	T3_C3_W1	T3_C3_W2	T4_C3_W1	T4_C3_W2	T5_C3_W1	T5_C3_W2
	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2

Table 2 *Matrix of configuration*

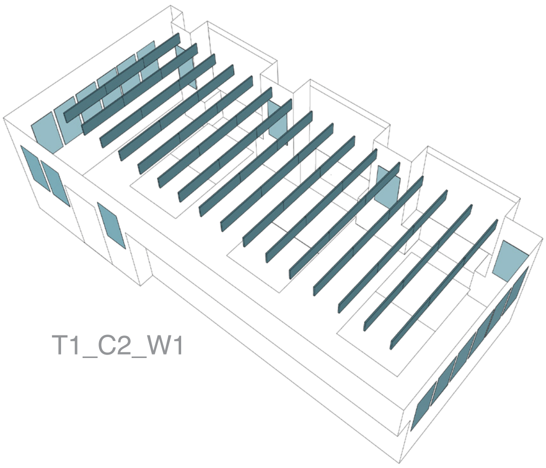
The combination of all the selected elements for the project results in 30 possible configurations, as shown in the following images.



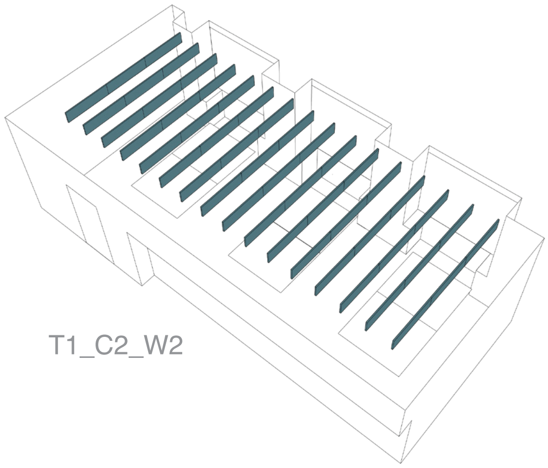
T1_C1_W1



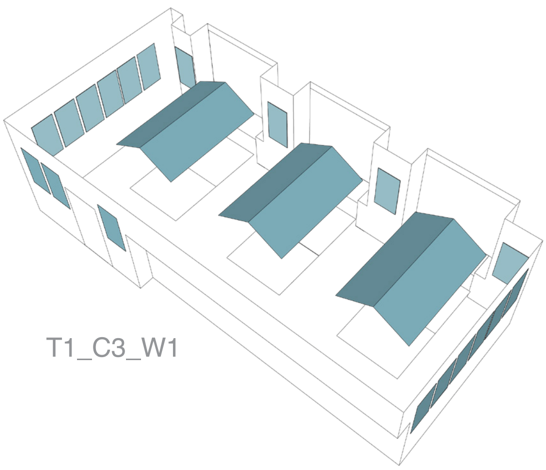
T1_C1_W2



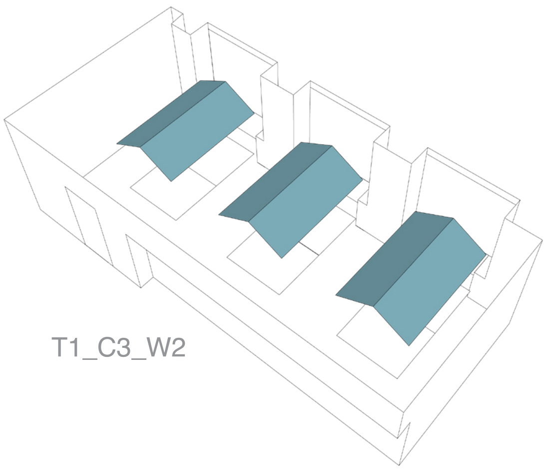
T1_C2_W1



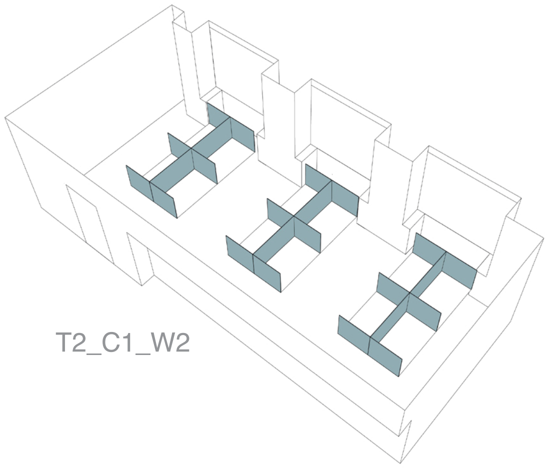
T1_C2_W2

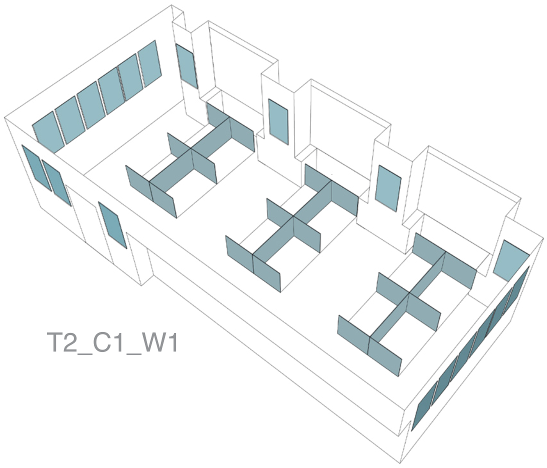


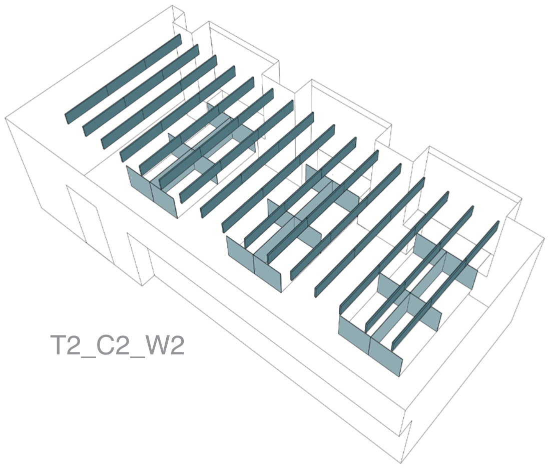
T1_C3_W1

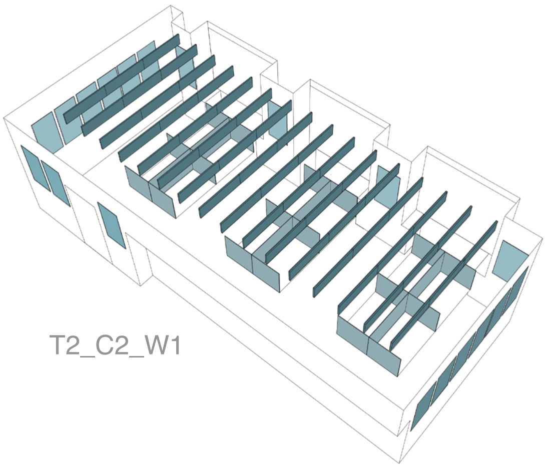


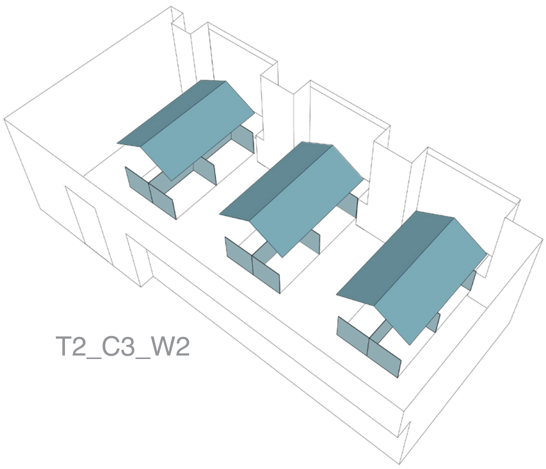
T1_C3_W2

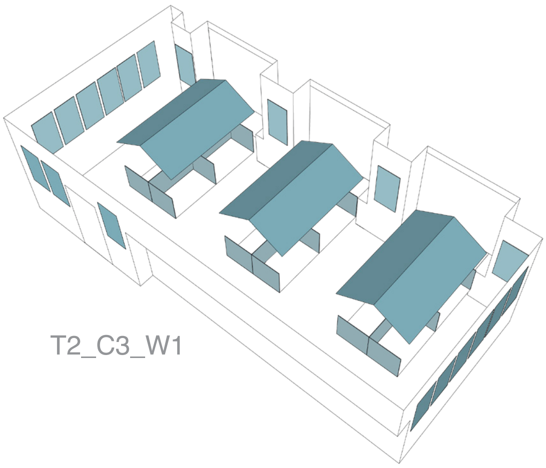

T2_C1_W2

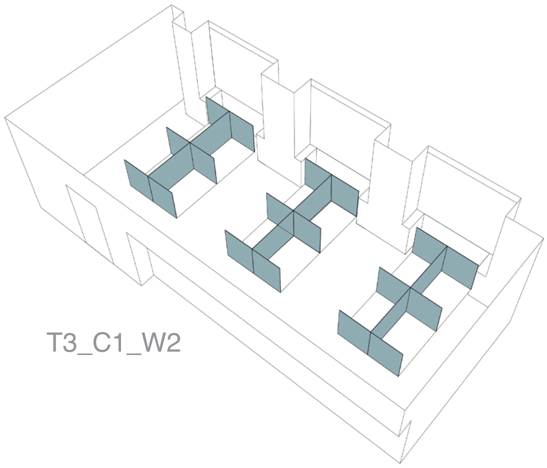

T2_C1_W1


T2_C2_W2

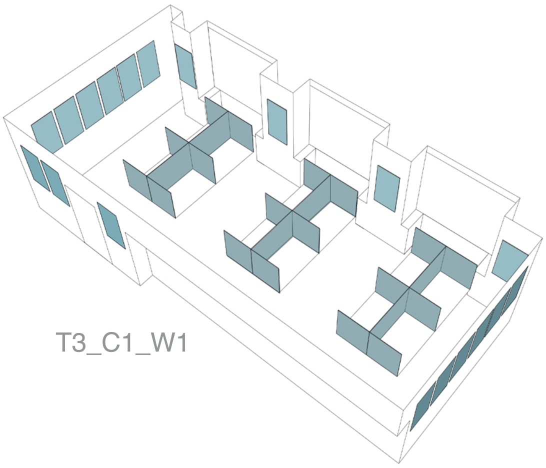

T2_C2_W1


T2_C3_W2


T2_C3_W1



T3_C1_W2



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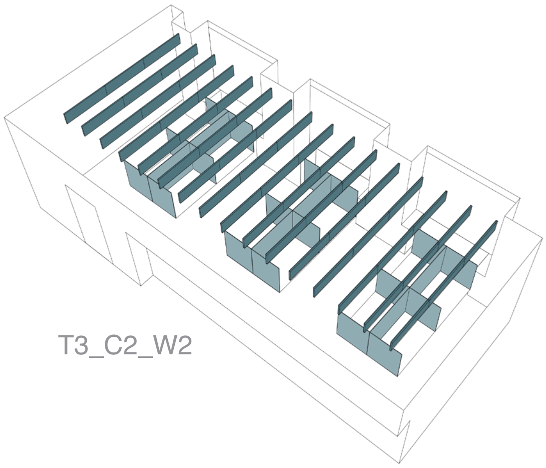

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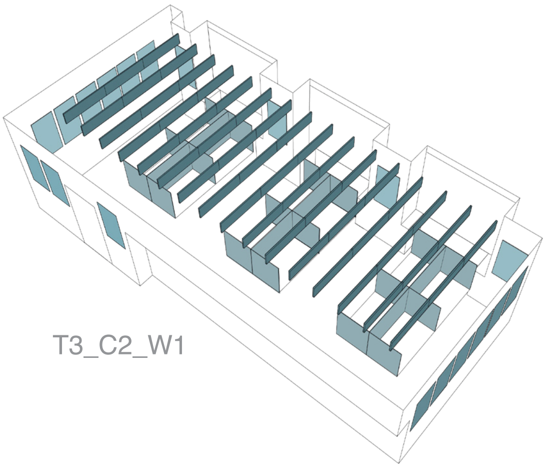

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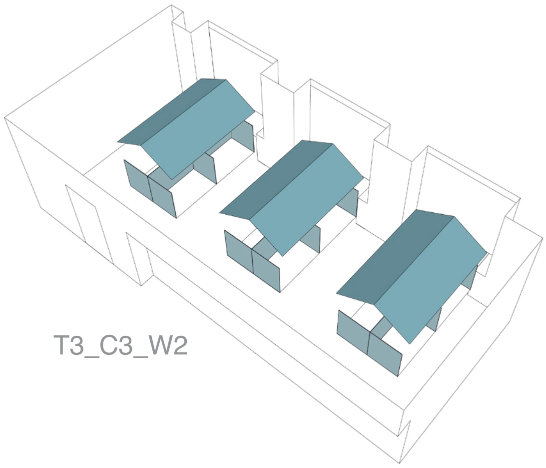

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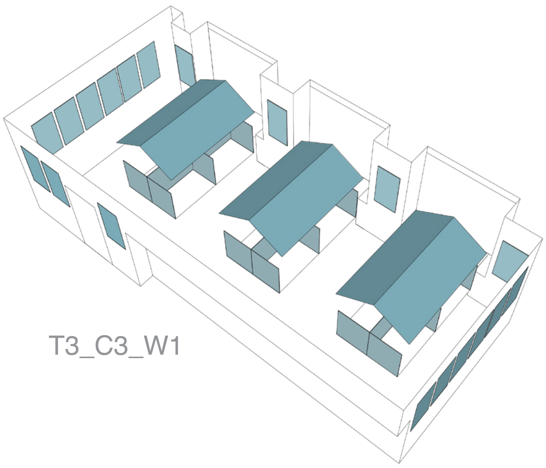

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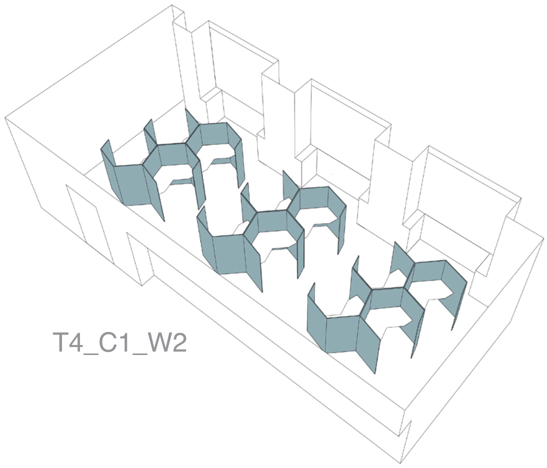
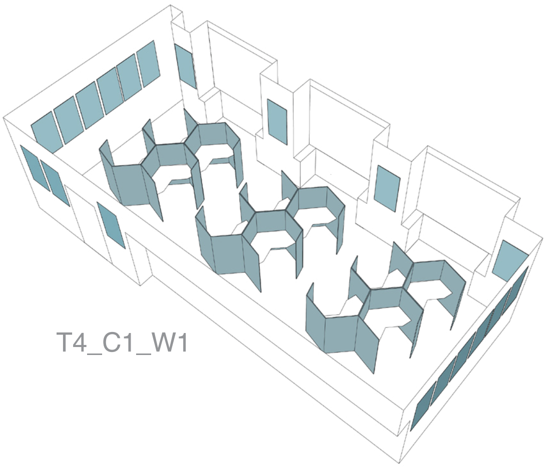


T4_C1_W2



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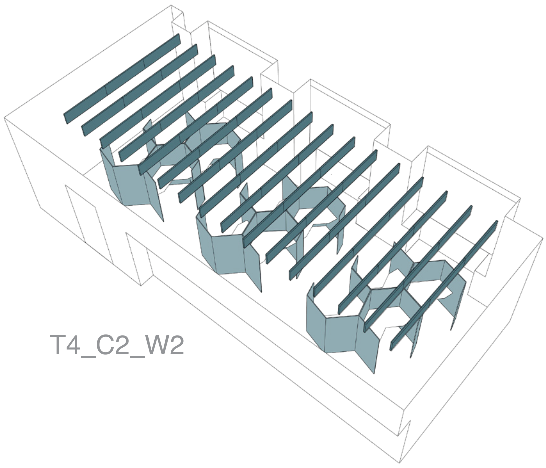

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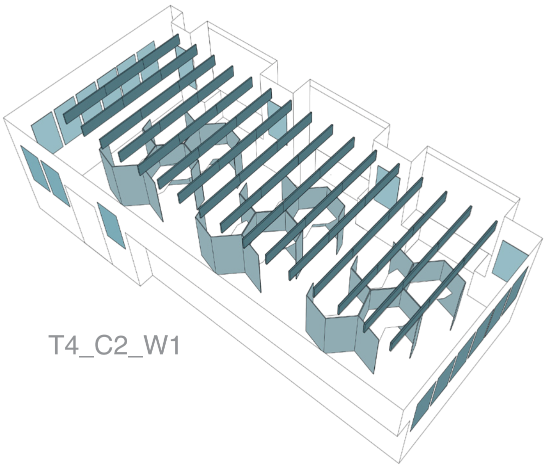

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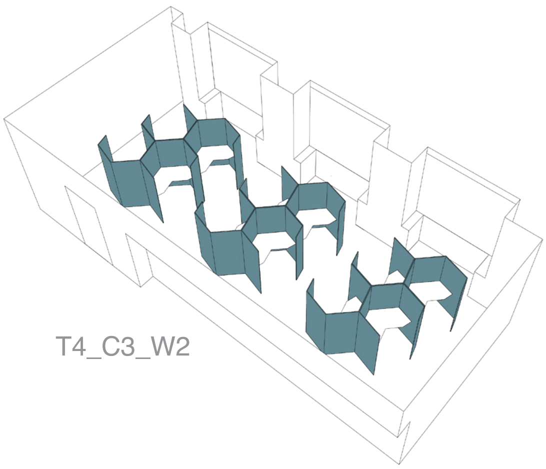

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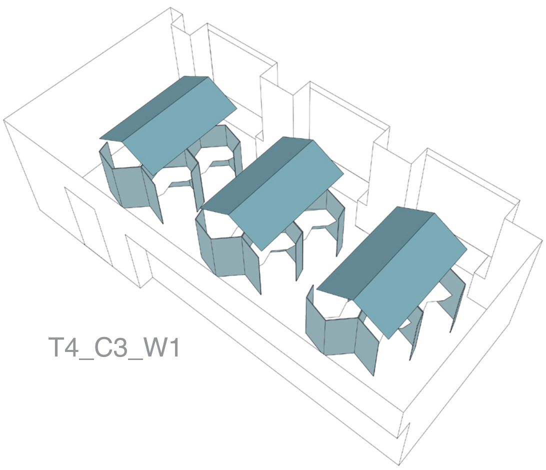

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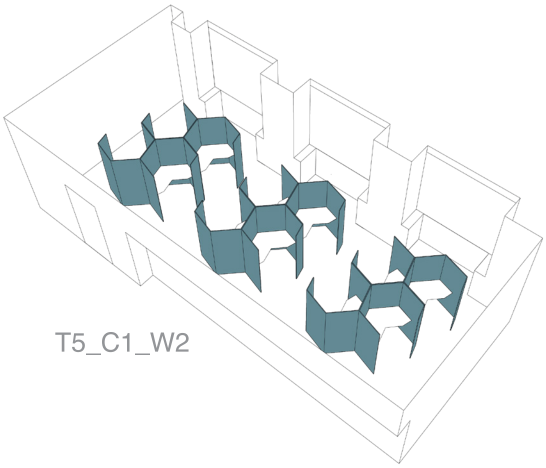
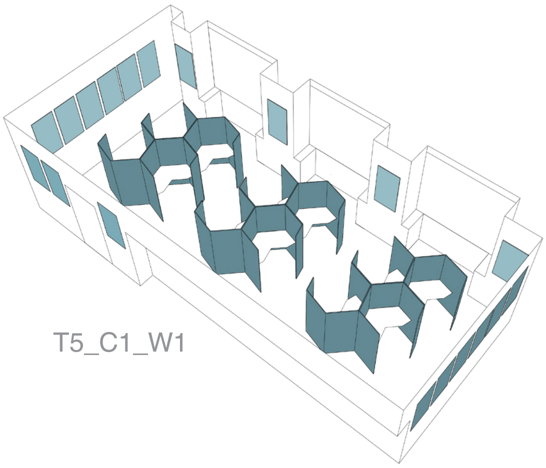
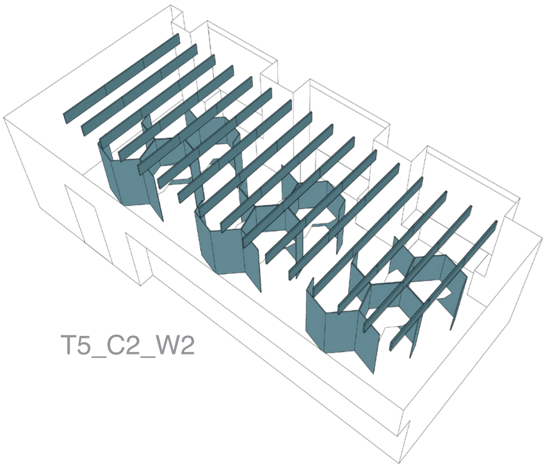


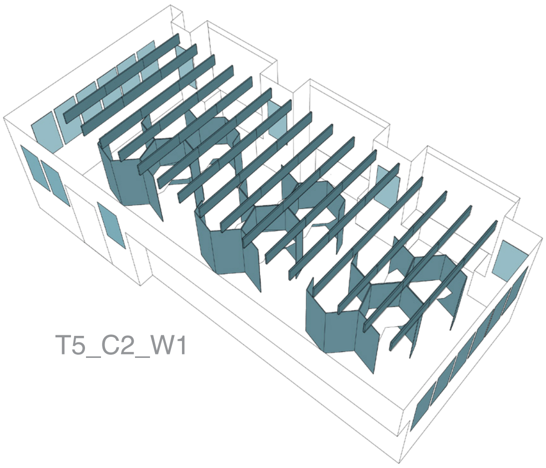
T5_C1_W2



T5_C1_W1



T5_C2_W2



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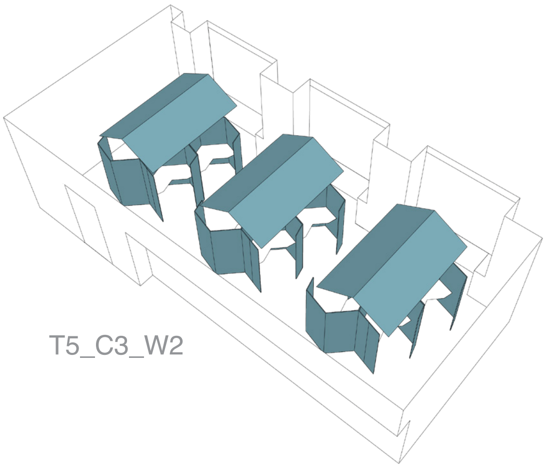
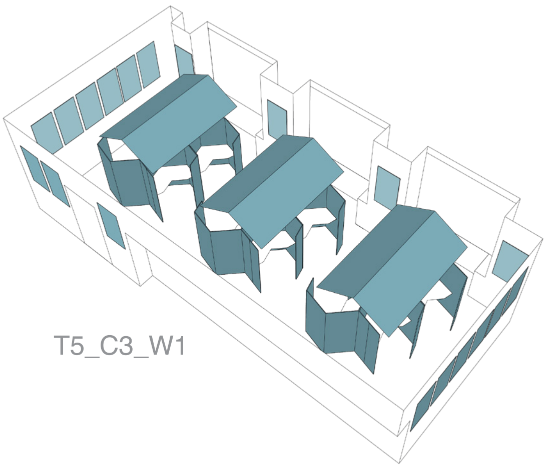


T5_C3_W2



T5_C3_W1

The next step involves modeling all configurations to create a 3D model analyzable by the Odeon software. Subsequently, simulations were conducted using the calculation software, and the results were presented in the following tables. For each configuration, the parameters described in ISO 3382-3:2022 as well as reverberation time and STI parameters were calculated.

Distraction Distance, Rd

This represents the shortest distance from the midpoint of the sound source where the STI falls below 0.50.

In cases where data is missing, it indicates that the STI never drops below 0.5.

The colors indicate the data quality according to ISO 3382-3:2022.

	Rd Distraction distance [m]									
	T1		T2		T3		T4		T5	
C1	12.5	10.8	4.4	4.8	4.3	4.7	-	-	-	-
C2	10.7	9.3	4.1	4.2	3.7	3.9	0.7	0.7	0.8	0.2
C3	10.3	10.3	3.8	4.9	3.6	3.6	1.2	1.6	1.1	0.7
	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2

Good values	<5
Medium values	5 - 11
Poor values	>11

Comfort Distance, Rc

This represents the shortest distance from the midpoint of the sound source where the A-weighted Sound Pressure Level (SPL) of speech is lower than 45 dB. The colors indicate the data quality according to ISO 3382-3:2022.

	Rc Comfort distance [m]									
	T1		T2		T3		T4		T5	
C1	129	581.4	12.2	26.1	8.9	16.4	4.4	8.8	3.4	5.4
C2	46	72.3	7.1	8.6	5.8	7.0	3.6	4.6	2.9	3.2
C3	40	64.7	6.8	11.9	5.6	6.5	4.6	5.8	3.7	4.4
	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2

Good values	<5
Medium values	5 - 11
Poor values	>11

Spatial Decay Rate of A-weighted SPL of Speech, D2,s

This represents the rate of spatial decay of the A-weighted sound pressure level (SPL) of speech per doubling of distance in decibels.

The colors indicate the data quality according to ISO 3382-3:2022.

D2,s Spatial decay rate of A-weighted SPL of speech, 125-8000 Hz [dB]										
	T1		T2		T3		T4		T5	
C1	2.2	1.7	3.4	2.5	4.2	3.0	3.2	2.1	3.8	2.6
C2	2.9	2.5	5.2	4.5	6.5	5.5	4.9	3.8	6.0	4.8
C3	2.9	2.6	4.6	4.0	6.2	5.4	4.7	4.4	5.8	5.1
	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2

Good values	>8
Medium values	5 - 8
Poor values	<5

Speech Level at 4 Meters Distance, Lp,A,S,4m

This represents the A-weighted SPL of speech in decibels at a distance of 4.0 meters from the midpoint of the sound source.

The colors indicate the data quality according to ISO 3382-3:2022.

Lp,A,S,4m A-weighted speech at 4 metres, 125-8000 Hz [dB]										
	T1		T2		T3		T4		T5	
C1	56.0	56.7	50.2	51.5	49.7	50.7	45.5	47.3	44.0	45.9
C2	55.0	55.7	49.3	50.0	48.6	49.4	44.2	45.7	42.2	43.4
C3	54.3	55.2	48.6	51.0	47.9	48.7	45.9	47.4	44.3	45.5
	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2

Good values	<48
Medium values	48-52
Poor values	>52

Reverberation Time, T30

This represents the time interval within which the sound energy decreases by 30 dB after the cessation of the sound source.

The colors indicate the data quality according to the French standard AFNOR NF S31-080.

T30 Average reverberation time [s]										
	T1		T2		T3		T4		T5	
C1	0.6	0.9	0.4	0.6	0.5	0.4	0.3	0.7	0.3	0.4
C2	0.4	0.8	0.3	0.5	0.3	0.5	0.4	0.5	0.5	1.0
C3	0.5	0.6	0.3	0.4	0.3	0.8	0.2	0.5	0.2	0.3
	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2

Good values	<0.5
Medium values	0.5-0.6
Poor values	>0.6

Speech Transmission Index, STI

The Speech Transmission Index is an indicator of the quality of speech transmission and reflects the quality of perception of a speaking source.

The colors indicate the data quality based on studies published by Professor V. Hongisto.

STI Speech trasmission index [-]										
	T1		T2		T3		T4		T5	
C1	0.6	0.6	0.6	0.5	0.6	0.6	0.4	0.5	0.4	0.4
C2	0.7	0.6	0.6	0.6	0.6	0.6	0.4	0.4	0.4	0.4
C3	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2

Good values	<0.2
Medium values	0.2-0.5
Poor values	>0.5

In addition to these simulations in the community office, two additional simulations have been integrated for the remaining two offices, Bench and Audit. The chosen configurations feature several elements to be tested, namely T2_C2_W1, which includes desk screens, ceiling baffles, and wall-absorbing panels; the other chosen configuration is T5_C3_W1, which includes cubicles, lowered ceiling elements, and wall-absorbing panels.

Bench

Rd Distraction distance [m]										
	T1		T2		T3		T4		T5	
C1										
C2			3.6							
C3									2.7	
	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2

Good values	<5
Medium values	5 - 11
Poor values	>11

Rc Comfort distance [m]										
	T1		T2		T3		T4		T5	
C1										
C2			7.7							
C3									4.8	
	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2

Good values	<5
Medium values	5 - 11
Poor values	>11

D2,s Spatial decay rate of A-weighted SPL of speech, 125-8000 Hz [dB]										
	T1		T2		T3		T4		T5	
C1										
C2			4.2							
C3									5.6	
	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2

Good values	>8
Medium values	5 - 8
Poor values	<5

Lp,A,S,4m A-weighted speech at 4 metres, 125-8000 Hz [dB]										
	T1		T2		T3		T4		T5	
C1										
C2			49							
C3									46.5	
	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2

Good values	<48
Medium values	48-52
Poor values	>52

T30 Average reverberation time [s]										
	T1		T2		T3		T4		T5	
C1										
C2			0.4							
C3									0.3	
	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2

Good values	<0.5
Medium values	0.5-0.6
Poor values	>0.6

STI Speech trasmission index [-]										
	T1		T2		T3		T4		T5	
C1										
C2			0.6							
C3									0.6	
	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2

Good values	<0.2
Medium values	0.2-0.5
Poor values	>0.5

Audit

Rd Distraction distance [m]										
	T1		T2		T3		T4		T5	
C1										
C2			4.7							
C3									2.5	
	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2

Good values	<5
Medium values	5 - 11
Poor values	>11

Rc Comfort distance [m]										
	T1		T2		T3		T4		T5	
C1										
C2			7.7							
C3									5.5	
	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2

Good values	<5
Medium values	5 - 11
Poor values	>11

D2,s Spatial decay rate of A-weighted SPL of speech, 125-8000 Hz [dB]										
	T1		T2		T3		T4		T5	
C1										
C2			6.1							
C3									5.3	
	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2

Good values	>8
Medium values	5 - 8
Poor values	<5

Lp,A,S,4m A-weighted speech at 4 metres, 125-8000 Hz [dB]										
	T1		T2		T3		T4		T5	
C1										
C2			50.8							
C3									47.4	
	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2

Good values	<48
Medium values	48-52
Poor values	>52

T30 Average reverberation time [s]										
	T1		T2		T3		T4		T5	
C1										
C2			0.6							
C3									0.3	
	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2

Good values	<0.5
Medium values	0.5-0.6
Poor values	>0.6

STI Speech trasmission index [-]										
	T1		T2		T3		T4		T5	
C1										
C2			0.6							
C3									0.5	
	W1	W2	W1	W2	W1	W2	W1	W2	W1	W2

Good values	<0.2
Medium values	0.2-0.5
Poor values	>0.5

The results, visible in the tables, show the desired consistency of the configurations as the environment varies. There are minor differences due to the different office geometries, but ultimately, the configurations behave similarly in all three offices.

The data presented in these tables are highly useful for understanding the acoustic behavior of these elements and which configurations are superior to others. There is no universally better combination of elements, as some elements excel in certain acoustic parameters while performing poorly in others.

However, trends can be observed among the various tables, and this can be useful for deriving important information. Looking at the critical distance table, where the STI value drops below 0.5, it is evident that values are mostly excellent except for configurations where there is a complete absence of any form of shielding, whether desk screens or cubicles. A similar conclusion can be drawn from the comfort distance results, where the distance beyond which the sound pressure level drops below 45 dB is considered. While the results are less distinct, the presence or absence of shielding acts as a dividing line between excellent and poor values. Excellent values are achieved with the use of cubicles, as they act as substantial sound barriers, average values with desk screens, and poor values in configurations lacking any form of shielding.

The table decribing the spatial decay of sound pressure level in relation to distance, and consequently how sound decays concerning distance from the sound source, is highly significant. While the results are not optimal with no green values present, it is clear that the best results are obtained with the presence of shielding. Most importantly, a variation in values can be observed based on the heights of screens. The results from this table may not be as anticipated, but they remain important as they highlight that achieving excellent sound pressure decay results requires even more radical design choices that in some cases challenge the concept of open-space offices.

The results of the table for sound levels at 4 meters distance particularly emphasize the difference in the choice of screens to use. Configurations with cubicles are all excellent, those with desk screens are average, and those without shielding have negative results.

The table of reverberation time results doesn't provide a clear indication, as no distinct trend is visible. It's noted that this parameter is tied to the amount of absorbing material surface. Therefore, it's evident that the best results are obtained with the presence of screens, especially cubicles. The difference between the presence and absence of wall-absorbing panels is clearly visible. In the table referring to STI values, it is clearly distinguishable that the best results are only visible in configurations where there are cubicles; however, optimal values are never reached.

In general, observing all the results, it can be concluded that the presence of wall panels improves all examined parameters. The best results are achieved with tall screens, and the use of suspended absorbing elements does not guarantee better results compared to ceiling baffles.

An essential concept to underscore is that, in an ideal acoustic design of an open-space office, all parameters should yield excellent results. However, achieving this is complex unless drastic solutions are employed. Thus, it's necessary to understand which solutions are best to obtain a precise result, which may give less weight to a single parameter compared to others. For instance, in an open-space office where teamwork is favored, and communication among staff is vital, it's preferable to exert more control over reverberation time and STI than sound pressure level decay. Conversely, in an open-space office focused on individual tasks requiring concentration, striving for excellent results in controlling sound level decay could be beneficial to enhance privacy and worker concentration.

The choice of desired outcome has architectural implications and can dramatically alter the office space and its usability.

08.2 Different configurations

The various needs that a company has, as mentioned, have significant implications for the design choices related to open-space offices. Within an office, different tasks can be carried out, ranging from those that require greater privacy to those that necessitate a continuous exchange of ideas among employees.

Chapter 3 has defined some types of layouts that can accommodate the various types of work, emphasizing the existence of numerous hybridizations during the design phase. In this part of the chapter, three different configurations out of the 30 belonging to the matrix have been analyzed; these represent three different ways in which a workspace can respond to different requirements dictated by the type of work that will take place within it.

To define three different types of work, a categorization found within the BS ISO 22955:2021 standard was used, specifically, space types 2, 3, and 4. Below, they are described in their functions, and the results of the simulations carried out are reported.

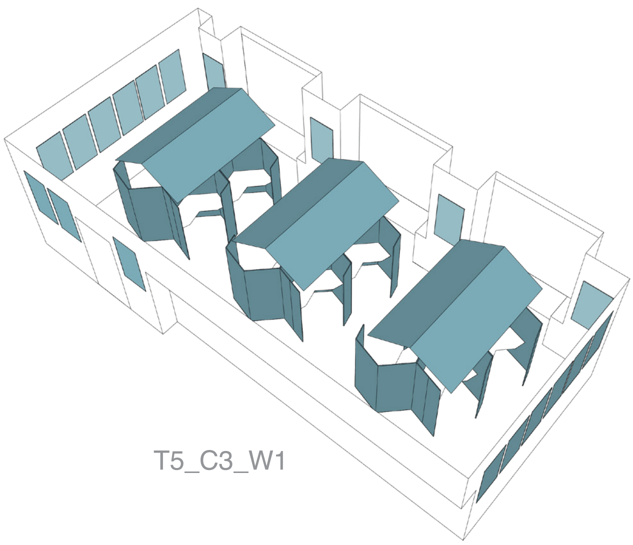
From the results of the tables, it is evident that as the type of work carried out within an office varies, the optimal reference parameters of ISO 3382-3:2022 are not always achieved. Therefore, in order to ensure specific working conditions, it becomes necessary to prioritize the attainment of optimal values for certain parameters that are more significant in achieving the required function for that space.

Space type 2

Activity mainly focusing on outside of the room communication (by telephone/audio/video)

The activities performed are diverse and mainly performed over the telephone: sales, technical assistance, information services, prospecting, surveys, emergency services, etc. They can be defined as non-diverse and non-collaborative.

Single values							
Description	Unit	Quantities	Poor values	Good values		SDF	Project
Distraction distance	m	rd	>11	<5		-	1.1
Spatial decay rate of speech	dB	D2,s	<5	>8		1.5	5.8
Speech level at 4 m distance	dB	Lp,A,S,4m	>52	<48		60.4	44.3
Comfort distance	m	rc	>11	<5		>>11	3.7
Background noise level	dB	Lp,A,B	<35 o >48	40 ÷ 45		44.1	43.8
Reverberation time	s	T30 0.5-4kHz	>0.6	<0.5		0.85	0.2
Speech Trasmission Index	-	STI	>0.5	<0.5		0.65	0.5



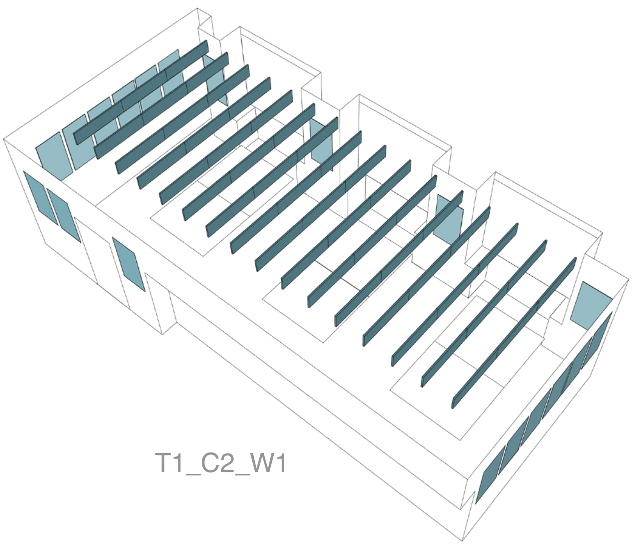
T5_C3_W1

Space type 3

Activity mainly based on collaboration between people at nearest workstation

This type of space is laid out mainly for collaborative or project group work. Communication between employees is often spoken aloud but also comprises telephone conversations. Persons can also be required to perform short individual tasks requiring limited concentration.

Single values							
Description	Unit	Quantities	Poor values	Good values		SDF	Project
Distraction distance	m	rd	>11	<5		-	10.7
Spatial decay rate of speech	dB	D2,s	<5	>8		1.5	2.9
Speech level at 4 m distance	dB	Lp,A,S,4m	>52	<48		60.4	55
Comfort distance	m	rc	>11	<5		>>11	46
Background noise level	dB	Lp,A,B	<35 o >48	40 ÷ 45		44.1	43.8
Reverberation time	s	T30 0.5-4kHz	>0.6	<0.5		0.85	0.4
Speech Trasmission Index	-	STI	>0.5	<0.5		0.65	0.7

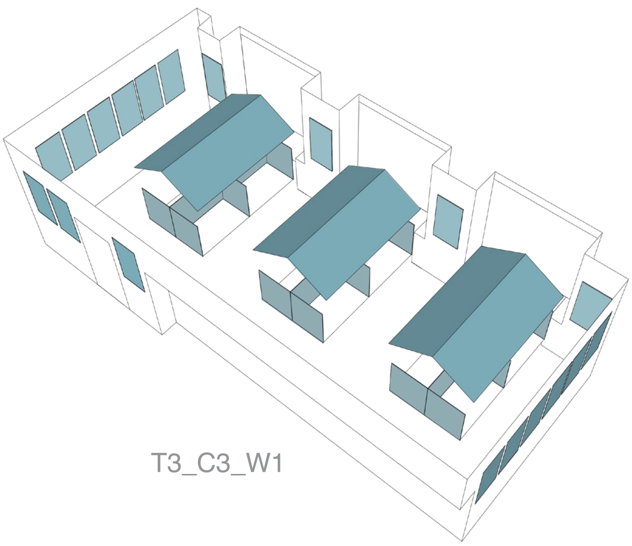


Space type 4

Activity based on a small amount of collaborative work

This type of space is laid out for mainly individual work, which may involve very occasional, short discussions. Typically, it is used for performing jobs that involve administration, accounting, human resources, procurement, etc.

Single values							
Description	Unit	Quantities	Poor values	Good values		SDF	Project
Distraction distance	m	rd	>11	<5		-	3.6
Spatial decay rate of speech	dB	D2,s	<5	>8		1.5	6.2
Speech level at 4 m distance	dB	Lp,A,S,4m	>52	<48		60.4	47.9
Comfort distance	m	rc	>11	<5		>>11	5.6
Background noise level	dB	Lp,A,B	<35 o >48	40 ÷ 45		44.1	43.8
Reverberation time	s	T30 0.5-4kHz	>0.6	<0.5		0.85	0.3
Speech Trasmission Index	-	STI	>0.5	<0.5		0.65	0.6

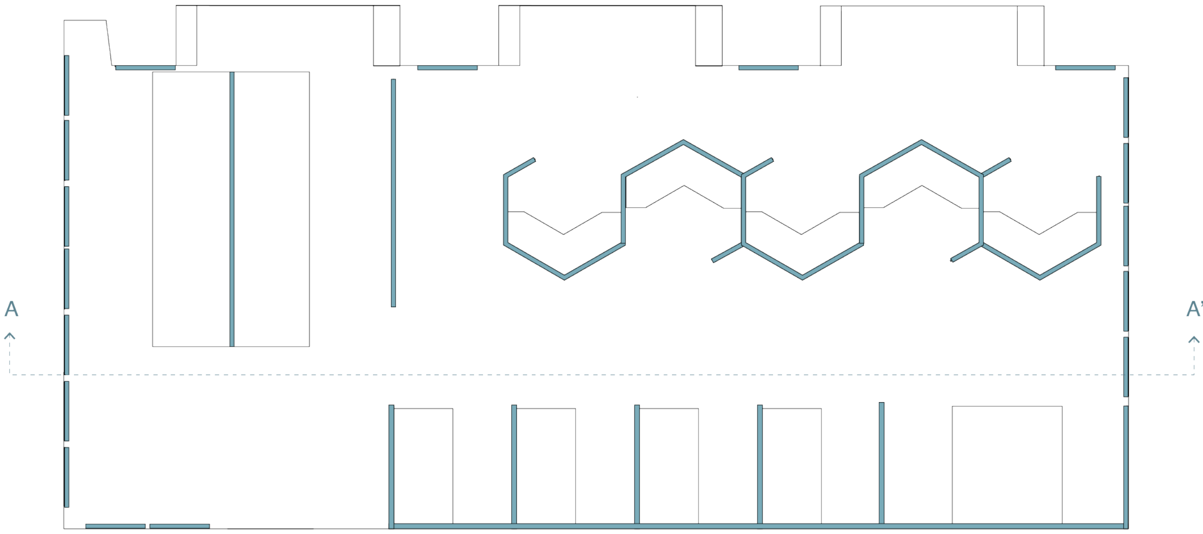


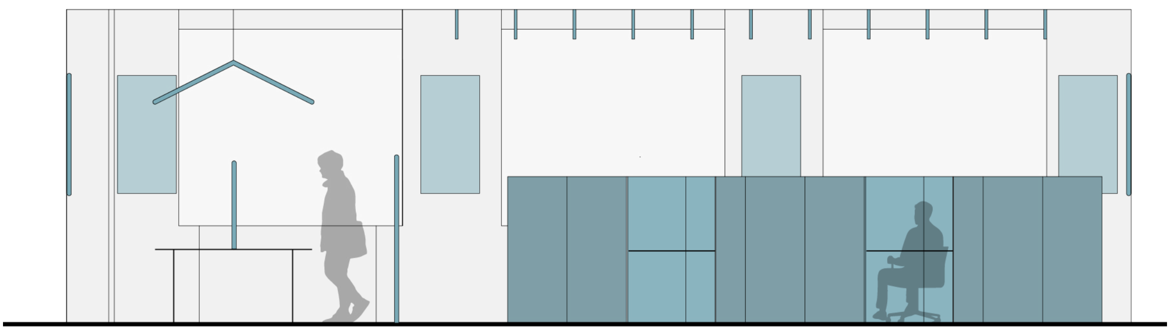
T3_C3_W1

08.3 Redesigning Community

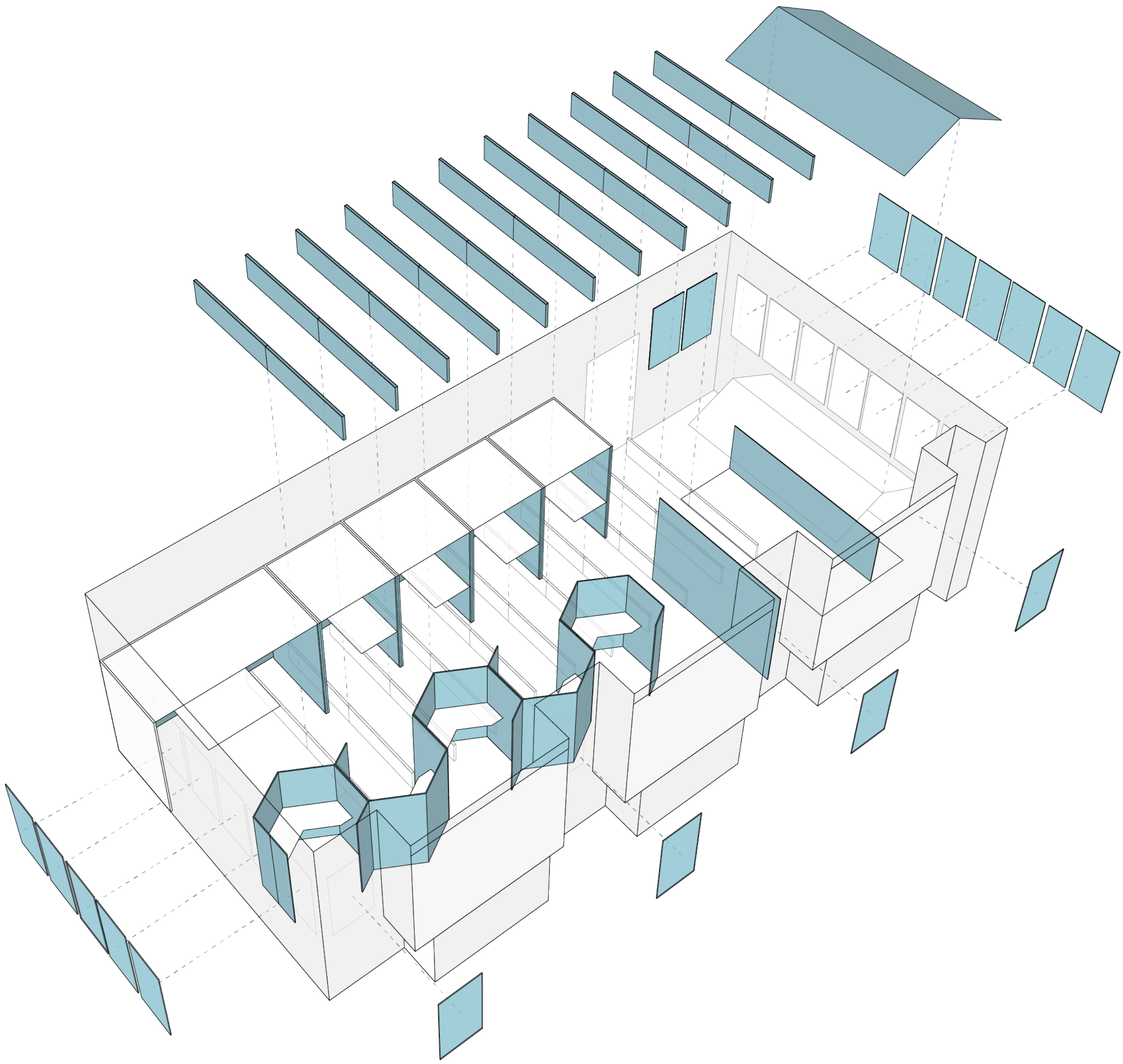
The project aims to experiment with an acoustic solution for an open-space office. The chosen office for testing acoustic improvement is the S0037 Community, selected due to its size and regularity. The results from the matrix and the considerations drawn from analyzing those results have served as starting points for the redesign of this office. An initial decision that strongly shaped the project was the intention to create an office space that includes both a dedicated area for group work and another area for workstations requiring a higher level of privacy. Closed cubicles have also been incorporated on three sides for tasks demanding increased concentration and privacy.

The elements utilized in the project correspond, in some instances, to real products available in the market. For example, suspended ceilings, baffles, wall panels, and desk screens are employed, and their absorption coefficients are known. Other items, such as cubicles and suspended ceiling elements, are not found in specific commercial catalogs but have been conceptualized based on existing similar references. The material chosen for these elements has high acoustic absorption properties, making them suitable for their intended function.





Section A-A'

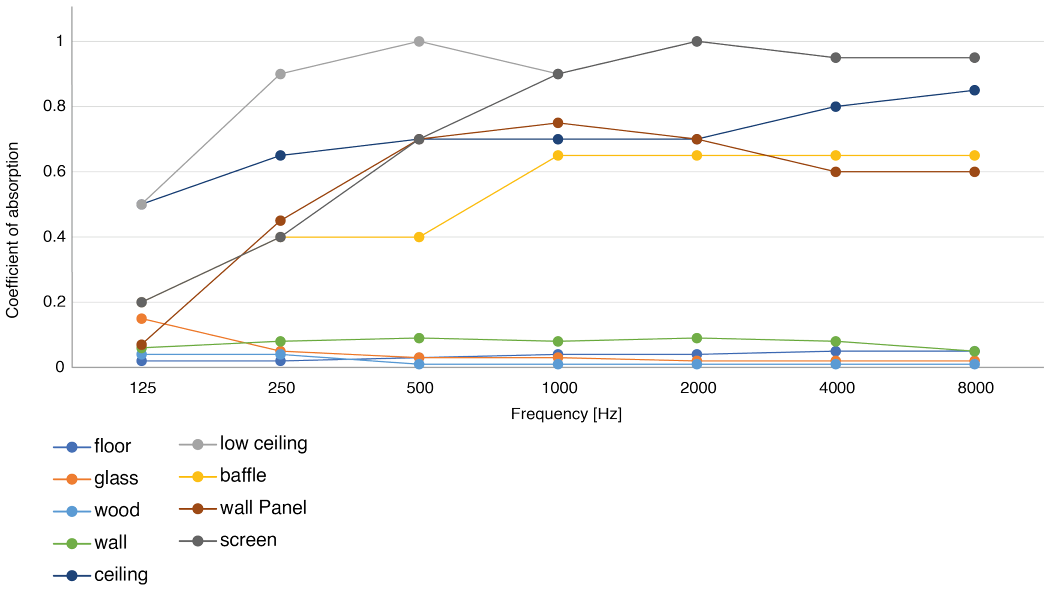


08.4 Results

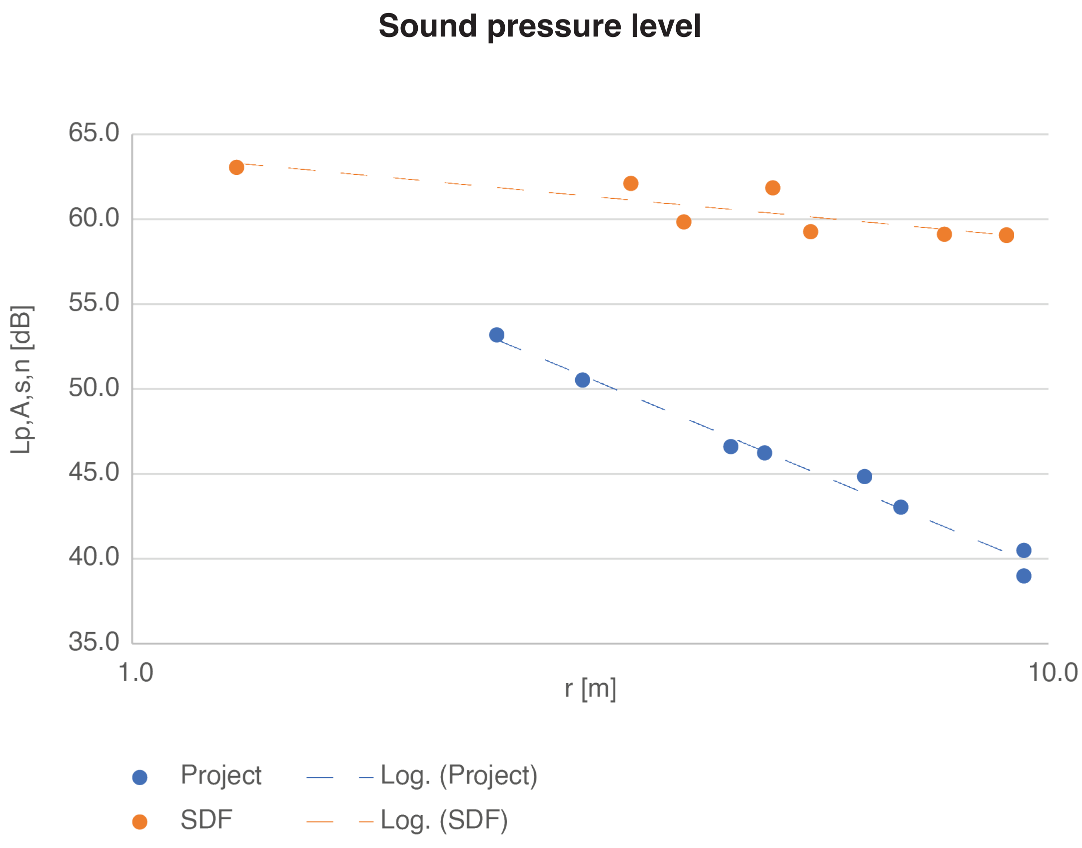
The Community project was subsequently translated into a 3D model for analysis using the Odeon software. This simulation provided us with data regarding the acoustic response of the office in relation to the ISO 338-3:2022 standard.

Below, in addition to the materials employed, the outcomes and graphs of the re-designed office are presented in relation to the data gathered during the site visit.

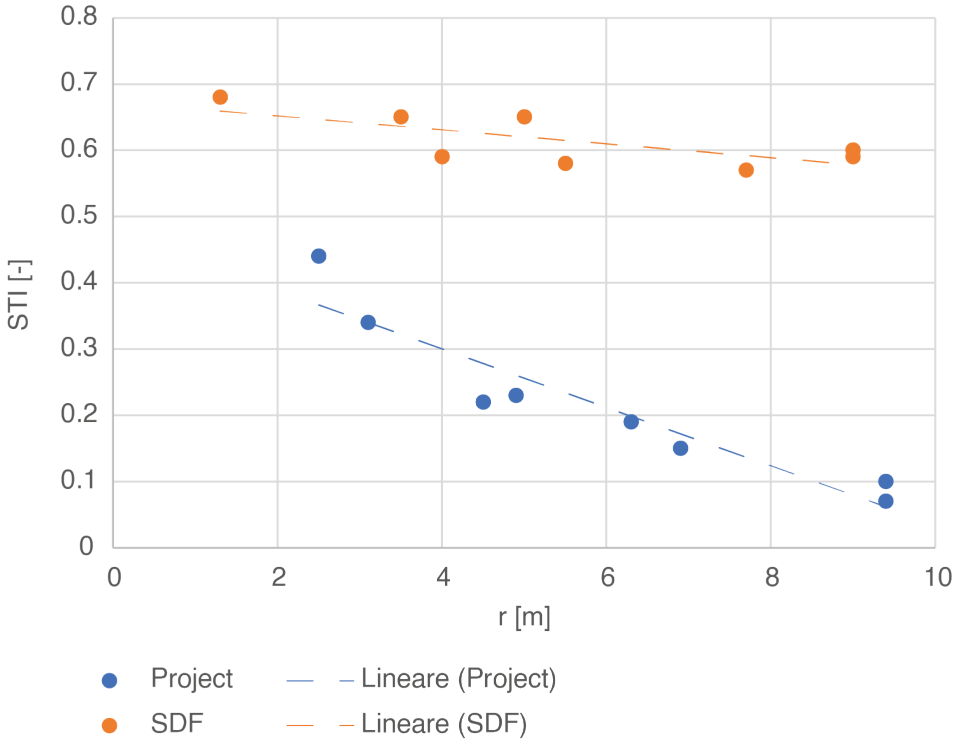
LIST OF MATERIAL AND COEFFICIENT							
	125	250	500	1000	2000	4000	8000
Floor (linoleum)	0.02	0.02	0.03	0.04	0.04	0.05	0.05
Glass	0.15	0.05	0.03	0.03	0.02	0.02	0.02
Desk (wood)	0.04	0.04	0.01	0.01	0.01	0.01	0.01
Door (wood)	0.04	0.04	0.01	0.01	0.01	0.01	0.01
Furniture (wood)	0.04	0.04	0.01	0.01	0.01	0.01	0.01
Wall	0.06	0.08	0.09	0.08	0.09	0.08	0.05
Ceiling Knauf Danoline Tangent T1 200mm	0.5	0.65	0.7	0.7	0.7	0.8	0.85
Focus A 20mm plenum 200 (capanna)	0.5	0.9	1	0.9	1	0.95	0.95
Baffle 1200x300x40 cc600mm	0.2	0.4	0.4	0.65	0.65	0.65	0.65
Akusto One 1200x600 (wall panel)	0.07	0.45	0.70	0.75	0.70	0.60	0.60
Screen	0.20	0.40	0.70	0.90	1.00	0.95	0.95



Single values							
Description	Unit	Quantities	Poor values	Good values		SDF	Project
Distraction distance	m	rd	>11	<5		-	0.7
Spatial decay rate of speech	dB	D2,s	<5	>8		1.5	6.7
Speech level at 4 m distance	dB	Lp,A,S,4m	>52	<48		60.4	43.2
Comfort distance	m	rc	>11	<5		>>11	3.3
Background noise level	dB	Lp,A,B	<35 o >48	40 ÷ 45		44.1	43.8
Reverberation time	s	T30 0.5-4kHz	>0.6	<0.5		0.85	0.2
Speech Trasmission Index	-	STI	>0.5	<0.5		0.65	0.5

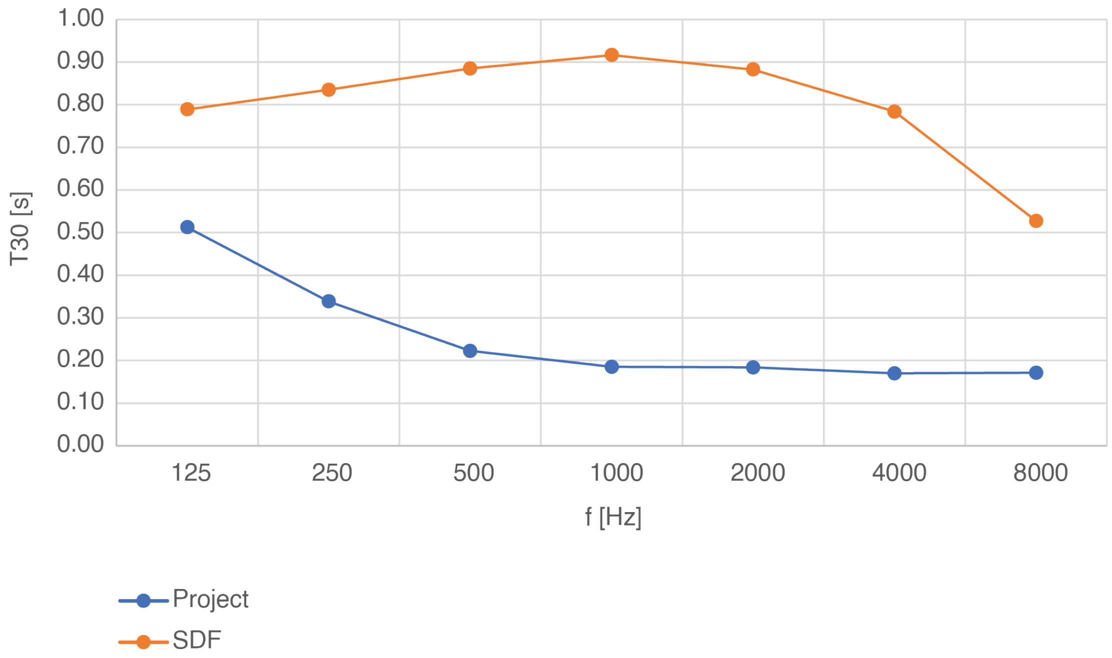


STI



0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
STI [-]
0
2
4
6
8
10
r [m]
Project
SDF
Lineare (Project)
Lineare (SDF)

T30



1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
T30 [s]
125
250
500
1000
2000
4000
8000
f [Hz]
Project
SDF

Conclusion

09

09. Conclusions

The simulation of the acoustic improvement project for the Community office shows excellent results. The table illustrates how all parameters, with the exception of D2,s, conform to the optimal values described in the ISO 3382-3:2022 standard.

Sound pressure values are generally lower due to the presence of numerous absorbing elements in the sound path. Of particular interest is the significant increase in the slope compared to the existing state, although this value, represented by D2,s, doesn't reach the optimal level specified by the standard.

The decision to divide the space into two parts did not allow us to achieve the optimal value for the D2,s parameter; however, the attained value is sufficient, thus enabling a more dynamic space suitable for various types of work.

The reverberation time curve also provides excellent results: in addition to significantly reducing the reverberation time, it's apparent that the curve is more linear in the mid-high frequencies and rises towards the lower frequencies, which are the most challenging to control.

Regarding the STI values, two significant improvements are noticeable: firstly, a general reduction in the value, and secondly, an increased slope of the line intersecting the values. This indicates that the STI value isn't constant but decreases as one moves away from the source.

I believe the achieved outcome is of high value since, in today’s context, the demand for open-space offices necessitates spaces with extensive flexibility that cater to various work styles, from individual tasks requiring concentration and privacy to group collaboration.