Politecnico
di Torino

MASTER’S DEGREE THESIS
BUILDING ENGINEERING
A.y. 2023/2024

A BETTER PLACE TO STUDY

A sustainable school hub in Albenga

Liceo Giordano Bruno school complex

Albenga (SV)

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ABSTRACT

On the occasion of the competition notice issued in 2016 by the Italian *Ministero dell'Istruzione, dell'Università e della Ricerca*, the aim of this study was to develop the design for a school complex in Albenga. The designated site for this project is a decommissioned military installation, whose layout served as a starting point for the design process. Concurrently, adherence to new guidelines pertaining to the design of educational facilities, along with the imperative to incorporate sustainable building practices, played a pivotal role.

Beginning with a comprehensive overview, the design aimed to allocate the necessary spaces for a school complex poised for the future, while also incorporating services intended to bridge the gap between the local community and the educational institution, all in accordance with the competition notice's specifications. Furthermore, an exploration of detailed aspects led to the adoption of various technological solutions, with the objective of advancing beyond traditional construction methods.

1. INTRODUCTION

1.1. PRESENTATION OF THE CASE STUDY

The aim of the competition notice issued in 2016 by the Italian *Ministero dell'Istruzione, dell'Università e della Ricerca* is to solicit innovative proposals for the design of schools distinguished by their architectural, engineering, technological, energy efficiency and structural seismic safety features, characterized by the presence of new learning spaces and a strong connection with the surrounding territory.

The assessment of the best proposal relies on architectural quality, seamless integration into the urban context, innovative architectural and technological solutions, functionality, flexibility in defining school spaces, accessibility, and economic sustainability. Each criterion contributes to the overall score for evaluating the best proposal.

Proposals should focus on the creation of innovative educational environments, starting from pedagogical and didactic needs and their relationship with space design. They should allow for the easy configuration of diverse and functional learning settings for differentiated activities, including group work, individualized tasks, presentations, multimedia production, individual or group assessments, thematic discussions and peer tutoring activities.

Additionally, it is essential to facilitate the execution of specialized laboratory activities, both by discipline and by the type of required equipment, while ensuring environmental, energy and economic sustainability. This involves practices such as rapid construction, recyclability of components and materials, high energy performance, use of renewable sources and ease of maintenance.

Furthermore, the integration of accessible green spaces that enhance the habitability of the site and the way the design solution interacts with the surrounding natural environment, landscape, and local context are crucial. This includes the continuity of green and natural spaces, accessible from daily learning spaces, creating an integrated extension of the school's educational environment.

The school should be designed as a reference point for the local community, actively involving stakeholders and promoting the permeability and flexibility of spaces. Creating attractive spaces to combat school dropout rates and conceiving the building as an educational tool for the development of technical and sensory skills are fundamental.

Spaces dedicated to research, reading, and documentation should be provided, optimized for the use of individual or group digital technological devices, with attention to individual well-being and social interaction through the creation of social and informal areas where the school community can interact and participate in both internal and community activities. (Ministero dell'Istruzione, dell'Università e della Ricerca, 2016)

1.2. REQUIREMENTS

The competition notice pertains to 52 geographical areas located in various Italian regions. Each area is associated with the design of a school facility at different levels of education. Specifically, this concerns a secondary school building in Albenga (SV), located in the Liguria region of northern Italy.

The project requires the construction of a school facility designed to suit a variety of educational demands. It necessitates designing a comprehensive infrastructure, including a network of 47 classrooms carefully planned to accommodate a student population of 1074, the integration of fifteen specialized laboratories, including three for computer science, eight for artistic disciplines, and two for physics and chemistry. The design also includes two libraries, which are intended to serve both educational and extracurricular purposes. Seven offices or teaching rooms are designated to support the administrative framework. Furthermore, two gyms are required to be designed to serve also as extracurricular activity locations. Another feature of the design is the inclusion of a multipurpose auditorium, which can accommodate a variety of events and activities. This facility acts as a hub for community participation. Furthermore, the design includes two archives and two storage rooms, which are placed to allow the orderly management of resources and administrative tasks. Finally, there are facilities including a bar and a refreshment area. (Ministero dell'Istruzione, dell'Università e della Ricerca, 2016)

1.3. NEW EDUCATIONAL NEEDS

In the realm of education, the design of school spaces has a significant impact on students learning. Educational environment design should not be limited to merely placing classrooms, but should be strategically crafted to promote interaction, concentration and creativity among students. This approach to school space design aims to create environments that inspire and support the educational process in all its facets. Through the implementation of flexible layouts, the use of appropriate colours, lighting and materials, and the integration of innovative technologies, it is possible to create stimulating environments that foster active and collaborative learning.

The pandemic has sparked a profound reflection on the design of school spaces, as it has highlighted the need to urgently address new challenges. In this context, the rethinking of educational environments has focused on ensuring climatic comfort, adequate air exchange, increased natural light and optimized acoustics. Additionally, there has been a growing emphasis on structural safety, ecology and accessibility, with the goal of making school buildings resilient to any emergency and opening them up to the community for other social activities beyond school hours. (Mario Cucinella Architects, 2021)

1.3.1. Educational environment and learning models interaction

The first shift in perspective regarding the evolution of educational spaces and school architecture in relation to changes in the teaching model, occurred, in Italy, in 2012. This happened when the Italian Ministry of Education (MIUR), with the scientific support of INDIRE, organized the conference "*Quando lo spazio insegna*". This event marked a turning point in the way school architecture was conceived, shifting the focus from aesthetic-practical aspects to its didactic effectiveness. It was recognized that the design of school spaces and furnishings should promote a new approach to teaching, centred on the student and characterized by more fluid and simple interactions.

Another central theme concerns the importance of digital technologies in the evolution of the educational environment, evidenced by the "*Scuola 2.0*" program and the introduction of the Interactive Multimedia Whiteboard (LIM) as a tool to promote interactivity and access to digital content. However, the change is not only about adopting new technologies, but requires a broader reconsideration of school spaces and furnishings.

The focus of the discussion revolves around the urgent need to deeply rethink the very concept of school, going beyond mere restructuring of its buildings and furnishings, to embrace a radical change that involves fundamental aspects such as schedules, the division of learning time between school and home, work tools and textbooks. This is a challenge that questions the entire educational model established over time. (Tosi & Mosa, 2019)

Learning tends to be seen as a process separate from the environment in which it occurs; however, it is the result of a complex interaction among individuals, the surrounding environment and teaching methods. Thus, the environments themselves can negatively or positively influence student learning outcomes.

Accordingly with the above-mentioned considerations, the importance of transitioning from a transmissive methodological model, based on a static classroom with fixed desks, to a more flexible and student-centred approach becomes essential. This new model requires open spaces, flexible furnishings and mobile technologies to support a variety of teaching approaches and learning activities. (Borri, 2018)

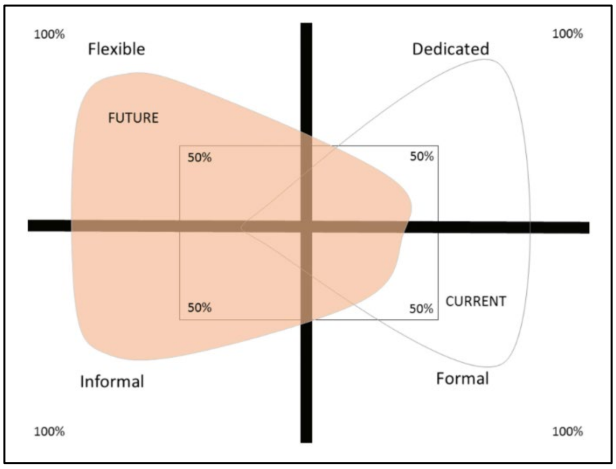

Figure 1. Vision of learning spaces[1]

International trends in school construction demonstrate how the standardization of architectural formats and the integration of digital technologies into learning environments are becoming common practice in school design. In this regard, national regulations and guidelines play a crucial role in shaping innovation in school construction, emphasizing the importance of an integrated approach that considers both pedagogical and technical aspects.

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[1] Retrieved from "The Classroom has Broken" - «indire.it»

Two specific cases of innovation plans in school construction were examined: the British program Building Schools for the Future (BSF) and the Australian Building Futures (BF). BSF was introduced as the largest school construction project in 2004, with the aim of modernizing every school in the United Kingdom, by promoting both the upgrading of buildings and the change of educational models through the integration of infrastructure and technological facilities. On the other hand, the BF program in the state of Victoria, Australia, aimed to enhance students' skills through the creation of innovative and flexible learning environments. (Tosi & Mosa, 2019)

Additionally, ongoing transformations in the German educational system are of primary interest, involving changes in teaching approach, school structure and requirements for school buildings. In this sense, three dimensions of school building quality are identified: usability quality, aesthetic quality and functional quality.

Usability quality focuses on the technical functioning of the building to ensure optimal learning conditions, including aspects such as lighting, ventilation, acoustics, temperature and Internet connectivity. Usability quality also includes considerations regarding safety, hygiene and the availability of necessary technical resources.

Aesthetic quality concerns the aesthetic perception of the building both from the inside and outside. The importance of a stimulating and relaxing environment to promote learning and student well-being is recognized. Additionally, the aesthetic quality of the building can influence individuals' behaviour and promote positive motivation.

Functional quality refers to the options offered by the spatial organization of the building to support students' and teachers' learning activities. This dimension concerns the layout of rooms, their size and the flexibility of spaces to adapt to different teaching and learning methods.

However, these three dimensions should not exist in isolation from each other but in an integrated manner. Learning requires a variety of methods and approaches to actively engage students. Pedagogy should be oriented towards active and inclusive learning, valuing diverse learning modalities and stimulating creativity.

Furthermore, learning benefits from the diversity of social forms, including individual, pair, group and classroom work. Schools should encourage collaboration and social interaction, promoting the individualization of teaching and respecting students' heterogeneity.

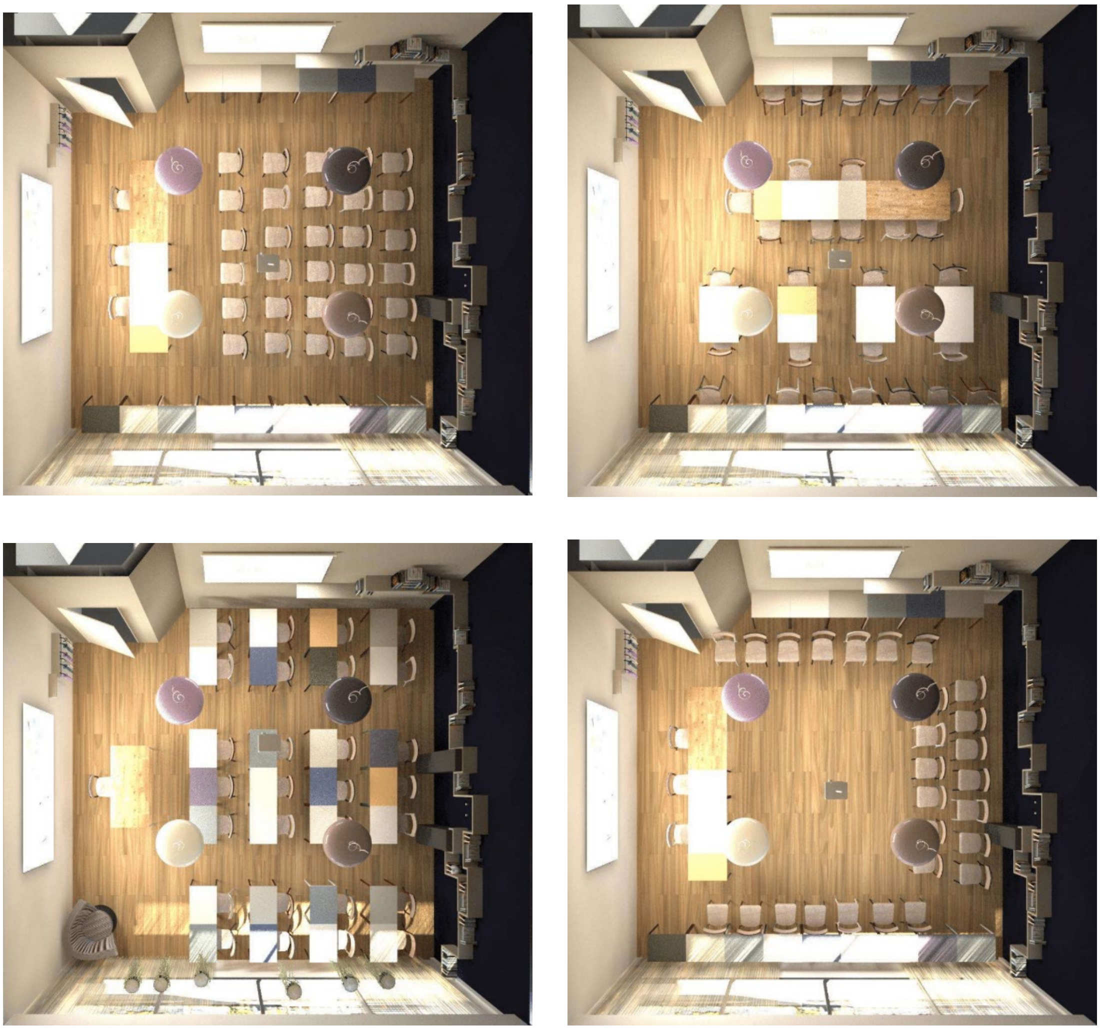

Figure 2. Individual desks configuration, working groups configuration conference configuration, collective configuration[2]

There are three fundamental types of spatial organization that have emerged in European school construction and can be considered as the "Aula Plus", the "Cluster" and the "Open Learning Landscape."

The concept of "**Aula Plus**" involves expanding the conventional classroom by adding additional space or connected group rooms. This allows for greater flexibility in teaching methodologies and better teacher control during lessons. However, it requires significantly more space compared to the other two types of classrooms.

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[2] Retrieved from "Lago" - «imparadigitale.it»

In the **Cluster** organization, three to six classes are grouped into a single spatial unit sharing a common open centre, called the "Forum" or "Marketplace." This offers flexibility in the use of common spaces and promotes closer cooperation among teachers. It is particularly suitable for larger schools.

The **Open Learning Landscape** involves creating a large open area without dividing walls, which can be temporarily subdivided with movable partitions or transparent installations. It is particularly suitable for promoting individualized working methods and self-managed learning.

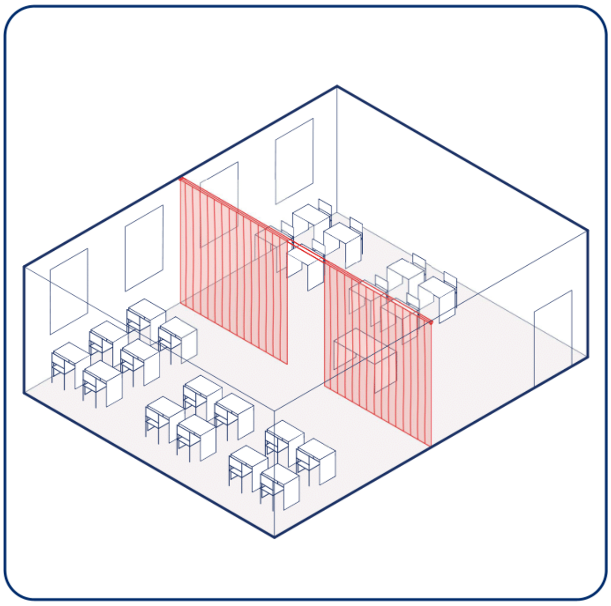

Figure 3. Classroom configuration with movable partitions[3]

Each type of spatial organization has specific advantages and disadvantages that must be considered in the design of a school. For example, the Aula Plus offers greater teacher control during lessons but requires more space and may limit student cooperation. The Cluster encourages collaboration among teachers and offers flexibility in the use of common spaces but is relatively rigid in the number of classes it can accommodate. The Open Learning Landscape promotes individualization and offers maximum flexibility in space utilization but requires discipline and precise agreements to avoid interference. (Borri, 2018)

The same view is shared by David Thornburg, in the framework known as "Campfires in Cyberspace", who describes five educational principles that have been adapted for the physical learning environment.

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[3] Retrieved from “Fare spazio. Idee progettuali per riaprire le scuole in sicurezza” - «fondazioneagnelli.it»

The "Campfire" describes situations where communication occurs from few to many, in a space that can accommodate a group of individuals. It is a frontal learning environment, where one or a few presenters communicate information to a larger audience.

The "Watering Hole" is an informal environment where people can gather freely, in groups of various sizes, to share information and interact spontaneously.

"Show Off" situations involve one person communicating to the rest of the world, demonstrating what they know or have done. It is an environment where communication goes from one to many, and feedback is essential for learning.

The "Cave" represents an isolated and contemplative place where individuals can reflect and focus without external distractions. It is an environment that promotes self-reflection and personal deepening.

"Laboratories" are environments where students can experiment and work practically on projects, interacting socially and experimentally. This environment supports learning through direct experience and peer collaboration. (Borri, 2018)

These educational principles represent the needs of individuals attending schools and should be integrated into the design. (Thornburg, 2004)

The expected results of a paradigm shift have been tested by European Schoolnet with the Future Classroom Lab (FCL), an environment designed to experiment with new teaching and learning approaches supported by information and communication technologies. The FCL focuses on six different learning areas, each aiming to promote innovative pedagogical approaches and adapt to the needs of learning activities. These areas are used for professional development seminars with teachers and have become models for creating similar learning labs in other European schools.

As it happens for any drastic change in social habits, this topic requires a process of reflection and adaptation of the educational approach within an innovative school. In this regard, the example of “Vittra School Telefonplan” in Sweden and the various phases that preceded its integration into community habits are reported.

Figure 4. Vittra School Telefonplan[4]

After the school opened, both teachers and parents expressed concerns about the effectiveness of the innovative learning environment. Teachers felt frustrated trying to adapt their pedagogical practices to the new context.

It was recognized that teachers needed to acquire new teaching methodologies and address challenges related to learning in a non-traditional environment. Uncertainty and anxiety related to the learning process were considered part of the educational journey.

Greater emphasis was placed on teacher professional development, focusing on how to design learning situations for teachers themselves and how to create opportunities for their continuous learning.

The innovative learning environment required a new form of leadership based on motivation rather than control. Teachers explored new models of student engagement and assessment, focusing on their learning and their ability to collaborate and step out of their comfort zone.

The school was conceived as an environment created to foster continuous learning, rather than to prepare for national exams. (Borri, 2018)

Among the various examples dedicated to the school of the future, one can certainly find that of the Emilia-Romagna region, which has outlined a series of virtuous guidelines for the design of school spaces. In these guidelines, also in relation to new pedagogical approaches, space is interpreted as a form of

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[4] Retrieved from «businessinsider.com»

education, in line with the school's vocation, as the quintessential place of learning where future generations spend a good part of their lives.

« Space as the third educator »

(Mario Cucinella Architects, 2021)

Lastly, another virtuous example in this regard is that of the Finnish context, which for years has encouraged the realization of connections between the school building and the learning process. School buildings are considered important for effective learning and school design is a carefully regulated process. The requirements for learning environments are based on national laws, regulations and directives. Objectives include creating safe, functional environments that promote the well-being of students and staff.

National guidelines for the design and evaluation of school buildings establish requirements such as flexibility, pleasing aesthetics, sustainability and safety. These criteria are fundamental for ensuring an effective and welcoming learning environment.

Eventually architects play a crucial role in school design, collaborating with educators and other experts to ensure that buildings meet educational needs and promote a positive learning environment. (Borri, 2018)

1.3.2. Engaging stakeholders in School Building Planning

Starting from the example just mentioned of the Finnish context, it has emerged how the involvement of various stakeholders in the design of school buildings is becoming increasingly necessary.

A crucial point concerns the active involvement of students and teachers in the design and reconfiguration of educational spaces. It is argued that such involvement is essential to ensure that learning environments are truly effective and meet the specific needs of the educational community. Moreover, learning environments should be designed to promote social interaction, collaboration, and student-centred learning.

The need to provide educators and architects with space and flexibility in the design of educational environments, in order to meet emerging needs in education and promote effective and inclusive learning, is of paramount importance.

To achieve the goal of creating functional school buildings suitable for educational needs, it is essential that all stakeholders involved learn to work together collaboratively and draw lessons from each project to improve subsequent ones.

Subsequently, the importance of providing training to building occupants at the time of delivery is highlighted to ensure effective use of the spaces.

The integration of evidence-based research into the design and use of learning environments is essential to maximize their effectiveness in promoting student learning and development. On the other hand, additional efforts are needed to encourage teachers to adopt innovative pedagogical approaches within these spaces.

There is a gap between the availability of innovative learning environments and the actual use of such spaces by teachers. Despite schools increasingly providing various types of flexible environments, many teachers continue to use traditional teaching methods that may not be effective in maximizing the potential of such spaces. (Borri, 2018)

As evidence of the above-mentioned considerations, the case of the municipality of Gentofte in Denmark is examined, which developed an intervention plan for innovation in school buildings, known as “The School of the Future (SKUB)”. This project stood out for its participatory design and attention to the specific needs of each school community. (Tosi & Mosa, 2019)

On a national level, the "Next Generation Schools" call is mentioned, promoted by the *“Compagnia di San Paolo”* Foundation, with the aim of maximizing the impact and effectiveness of investments provided by the National Recovery and Resilience Plan (PNRR) related to the Ministry of Education's "*Futura, la Scuola per l'Italia di Domani*" Program.

The call fits into the context of the PNRR and aims to support local public authorities in acquiring skills and strengthening their technical structures. The centrality of education in the Foundation's strategies is highlighted, emphasizing the importance of integrating structural and architectural aspects with educational, digital connectivity, environmental and managerial aspects.

The call aims to consolidate the skills of local authorities in the interdisciplinary design of innovative, sustainable, and inclusive schools, kindergartens, gyms and canteens. It proposes to accompany the various phases of design of the interventions provided by ministerial notices, offering training, capacity building and support on specific topics, including participatory paths involving the educational community.

The Foundation provides local authorities with support documents containing interdisciplinary guidance suggestions for the design of schools, kindergartens and preschools. These documents include useful indications for promoting integration between architectural and educational-didactic design, as well as for developing a clear interdisciplinary idea of the educational space.

The main objective of the call is to maximize the impact of PNRR investments in the education sector, consolidating the skills of local authorities in design and accompanying the various phases of implementation of interventions. It also aims to promote the open use of school facilities as spaces for innovative learning, education, culture promotion, well-being and socialization. (Fondazione Compagnia di San Paolo, 2022)

In this sense, the example of Emilia-Romagna sets the standard. In the guidelines, it is described how the active involvement of the city community is a focal point of the design phase, which, along with other factors, influences the sense of civic belonging. (Mario Cucinella Architects, 2021)

In summary, the design of school facilities should focus on the development of educational environments, student well-being and their preparation for a continuously changing world, adopting innovative approaches that promote student interest and engagement, preparing them to face future challenges with competence and awareness. (Tosi & Mosa, 2019)

1.3.3. Schools as civic centres

Looking at the issue from a different perspective, emphasis is placed on the possibility of involving the entire community in the use of school buildings, placing them at the centre of city social activities.

In this perspective, it is not only the physical spaces of schools that are examined, but also their social and cultural role. There is reflection on the need to transform schools into true civic centres, open and attractive to the entire community, rather than limited learning environments.

In this regard, another virtuous example comes from Northern Europe, specifically Iceland, where the issue of school dropout rates has been addressed through the creation of multifunctional and attractive environments for students.

Furthermore, the importance of promoting lifelong learning is discussed, emphasizing the concept of "informal learning" and the role of fab labs in promoting the acquisition of practical and transversal skills. (Tosi & Mosa, 2019)

In the development of the so-called "Community-City" proposed by Emilia-Romagna, there are several strategies to adopt. Firstly, opening the school 24 hours a day, thus even outside of school hours, entrusting the management of spaces to local associations, which can organize several activities for the city. Then, from a functional point of view, creating diversified entrances to allow partial use of the building outside of educational activities. Finally, making outdoor spaces such as courtyards and gardens easily accessible to further involve neighbourhood activities. (Mario Cucinella Architects, 2021)

1.4. SUSTAINABILITY IN DESIGN

Construction has traditionally been associated with high resource consumption and greenhouse gas emissions, representing a significant part of the global environmental impact. The growing concern about climate change and awareness of the limitedness of natural resources have led to the need for a new approach to construction. Eco-friendly construction aims to address these challenges by embracing sustainability as a primary goal in building design and implementation.

Sustainable architecture designs and constructs buildings capable of minimizing environmental impacts, embracing principles of reduction and limitation to achieve resource efficiency and minimal pollution throughout the entire lifecycle.

In the context of construction, the term "resilient" describes buildings' ability to withstand extreme events or natural disasters and recover quickly and effectively afterward. Building resilience is essential in sustainability and ecological construction, as resilient buildings are designed and built to be less vulnerable to events such as earthquakes, floods, hurricanes, fires, and other natural disasters. To ensure building resilience, a holistic approach is necessary, considering aspects such as seismic design, water resource management, flood protection, and energy efficiency. Urban planning and assessment of local vulnerabilities are also vital to adequately protect and prepare buildings against adversity. (Vanoncini, 2023)

The sustainability of a building encompasses various aspects, including design, choice of technologies and materials, building maintenance, impact on the surrounding environment and urban context, and end-of-life decommissioning. LEED certification utilizes a point-based system to evaluate building sustainability, considering various aspects related to design and construction.

The building lifecycle involves phases such as extraction and transportation of raw materials, transformation into finished products, construction, usage, and end-of-life decommissioning. Environmental impact assessment, conducted through life cycle assessment (LCA), analyses impacts occurring before, during, and after the building's existence and assesses impacts generated in other places than the settlement. (Maywald & Riesser, 2016)

Sustainable architecture aims to integrate construction into the environment and nature, prioritizing the common good over individual profit. It considers buildings as part of an interactive and dynamic system, incorporating natural and social elements into the project. Materials used in construction should pose no health risks and preferably contribute to environmental sanitation. Sustainable architecture addresses energy scarcity by employing bioclimatic approaches, insulation, renewable energy sources, and efficient systems. It also focuses on water resource management, material selection based on life cycle assessment, stakeholder involvement, and promoting integration into the community. Dry construction systems and modular elements are favoured for easy dismantling and reuse, aligning with principles of minimizing land consumption and raw material use. (Studio Tecnico Geom. Fausto Bartolucci)

1.4.1. Ecological materials selection

The selection of materials is fundamental in sustainable architecture, driving a revolution in the construction sector towards eco-friendly alternatives. Traditional materials with high environmental impact are progressively being replaced by more sustainable and low-impact solutions. Eco-friendly materials are at the forefront of modern ecological construction, chosen for their minimal environmental footprint, reduced greenhouse gas emissions during production, and recyclability. (Vanoncini, 2023)

Certified wood from sustainably managed forests stands out as a highly valued material in sustainable architecture. It is renewable, has a low environmental impact, and offers excellent insulation capabilities, reducing the need for heating and cooling. Additionally, its use promotes the recycling of atmospheric carbon, aiding in combating the greenhouse effect.

Bamboo is another increasingly popular material due to its rapid growth and resilience. It serves as a sustainable alternative to traditional wood, as it can be harvested without damaging the plant's roots, which continue to grow and regenerate quickly. This makes bamboo ideal for structural and finishing applications in sustainable buildings.

The integration of photovoltaic panels is also on the rise in sustainable architecture. These panels convert solar energy into electricity and can be seamlessly incorporated into building facades and roofs, providing clean and renewable energy. Their use reduces reliance on non-renewable energy sources and helps cut greenhouse gas emissions. (Vanoncini, 2023)

The adoption of eco-friendly materials in construction offers numerous advantages for both the environment and building occupants. Environmentally, these materials decrease the consumption of natural resources, minimize the extraction of virgin materials, and facilitate waste recycling. Moreover, they lower greenhouse gas emissions during production, contributing to climate change mitigation.

From the perspective of occupants, eco-friendly materials enhance indoor air quality, creating a healthier and more comfortable living environment. Materials with low CO2 emissions help reduce volatile organic compounds (VOCs) in indoor air, thereby promoting respiratory health. (Vanoncini, 2023)

1.4.2. Technological innovation

Technological innovation plays a pivotal role in ecological construction by facilitating the optimal utilization of eco-friendly materials and enhancing buildings' energy efficiency.

Digital technologies, such as Building Information Modelling (BIM), enable precise design and efficient resource management during the construction phase. Additionally, the integration of sensors and intelligent systems for building monitoring optimizes energy consumption, reduces waste, and enhances system efficiency. (Azhar, 2011)

Optimizing the construction site is crucial for sustainable construction, achievable through careful planning and innovative technologies. For instance, the adoption of 3D modelling and BIM streamlines the construction process, reducing time and materials required. Prefabrication of construction elements in factories minimizes waste and enhances work quality.

Moreover, enhancing the energy efficiency of construction machinery contributes to reducing environmental impact and optimizing resource utilization. Low-energy consumption equipment and the use of renewable energy sources during construction further enhance sustainability. (Vanoncini, 2023)

Regarding site optimization and the construction phase of the building, the potential of prefabrication plays a leading role. The approach to modular construction involves the prefabrication of modular components on a large scale in an off-site production facility for rapid on-site assembly, gaining increasing attention in the construction sector.

Prefabricated buildings, constructed off-site, minimize disruption to the environment. Material waste and energy use are significantly reduced due to controlled factory conditions. The completion time for modular buildings is nearly 50% faster than traditional construction, while high-energy efficiency systems like high-efficiency glass and solar panels contribute to long-term sustainability.

Modular buildings, also known as portable buildings, can be transported and reused without demolition, minimizing environmental disturbance. This versatility, along with reduced energy consumption during construction and occupancy, underscores the sustainability of modular construction. (Italian Quality Experience)

1.4.3. Sustainable architecture as an investment for the future

Embracing sustainable architecture represents a strategic investment for the future, offering not only environmental benefits but also substantial long-term economic advantages. A key source of savings from eco-friendly buildings lies in the reduction of operational costs.

Sustainable buildings are engineered to be highly energy-efficient, resulting in significant reductions in energy expenses for both occupants and owners. Additionally, these structures boast enhanced durability over time, thanks to the use of premium materials and thoughtful design solutions. This translates to fewer maintenance interventions over the years, further diminishing management and upkeep expenses.

Moreover, the adoption of sustainable architecture can positively impact the health and well-being of occupants. Interior environments crafted with a focus on air quality and natural light foster comfort and productivity, leading to increased satisfaction and performance in both work and residential environments. (Vanoncini, 2023)

2. METADESIGN

2.1. SITE ANALYSIS

2.1.1. Geo-location

The area of intervention is localized in the Albenga municipality, right outside the city centre. The main axis of the area is North – South and currently access to the site is from the North side.

Figure 5. Location of the area of intervention[5]

2.1.2. Surrounding area analysis

The area surrounding the lot is already densely built: at the western side of the site is the *Santa Maria di Misericordia* hospital and at the other side of the area is the municipal stadium. Moreover, right after the hospital, an industrial area is developing, being various shopping centres, superstores and many others.

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[5] Retrieved from Google Maps - «google.com»

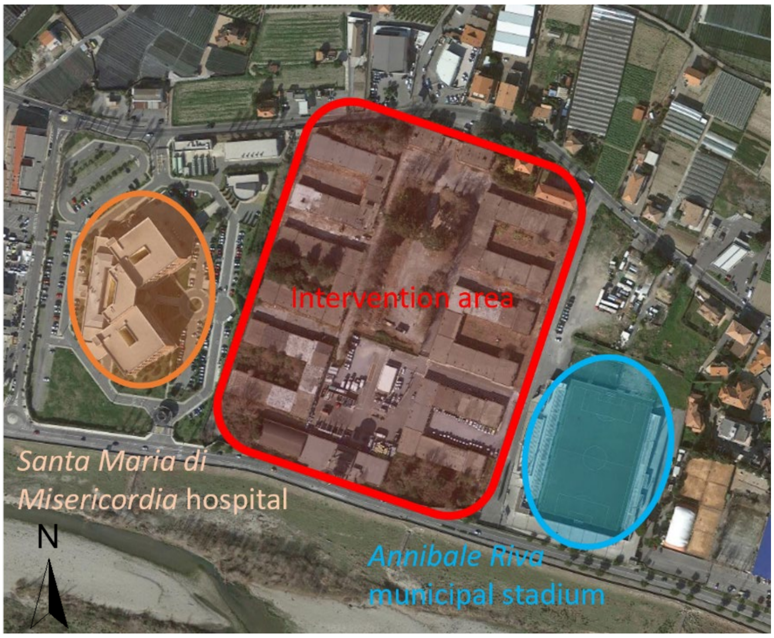

Figure 6. Building typology surrounding the area[6]

However, on the other hand, the northern side of the surroundings is a rural area, mainly destinated to agriculture.

Eventually, on the southern border is the *Centa* River.

Considering road connections, the site is bordered by two roads: the *Viale Martiri della* foce at South, which also includes a pedestrian and bicycle path, and the *SP582* provincial road at North.

Two lines of public transport which run along the roads are present, one specifically to reach the hospital, the other connecting the city centre to its surroundings.

The presence of car parking is strictly related to the hospital and the shopping centre.

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[6] Retrieved from Google Maps - «google.com»

2.2. CLIMATIC ANALYSIS

A crucial aspect of green building design is to achieve a comfortable indoor environment for occupants while minimizing reliance on energy-intensive mechanical systems. The indoor environment is significantly influenced by outdoor climatic conditions, which are analysed based on the site's coordinates. Weather data collected via *Meteonorm* software for the case study location are further examined using *Climate Consultant* software, considering variables such as temperature, radiation, relative humidity, wind patterns, sun path, sky cover, illumination, and precipitation. Subsequently, a psychrometric chart is generated to explore and devise design strategies for optimizing indoor thermal conditions.

2.2.1. Temperatures and radiations

Examining the temperature ranges for each month, along with their respective mean values and comparison to the comfort zone, reveals a trend towards colder weather from October to April, with temperatures falling below the comfort range. This suggests the necessity of implementing heating systems and adequate insulation measures to maintain comfortable indoor conditions.

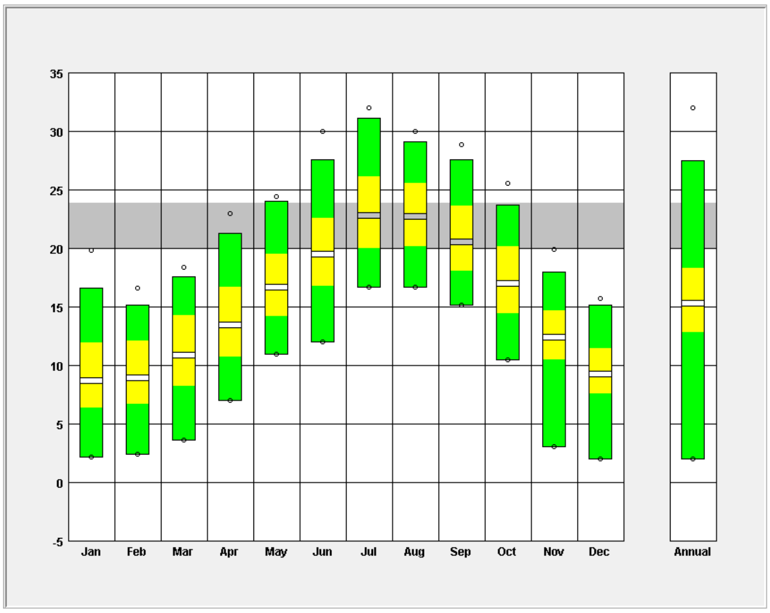

Figure 7. Temperature ranges[7]

Radiation values also play a crucial role in this analysis, with peak radiation occurring during the summer months. The correlation between radiation and temperature is particularly pronounced for global horizontal radiation, while it is less pronounced for diffuse and direct normal radiations. Understanding these

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[7] Retrieved from Climate Consultant software

relationships aids in analysing heat gain through radiation during both summer and winter, and facilitates the design of effective photovoltaic panels.

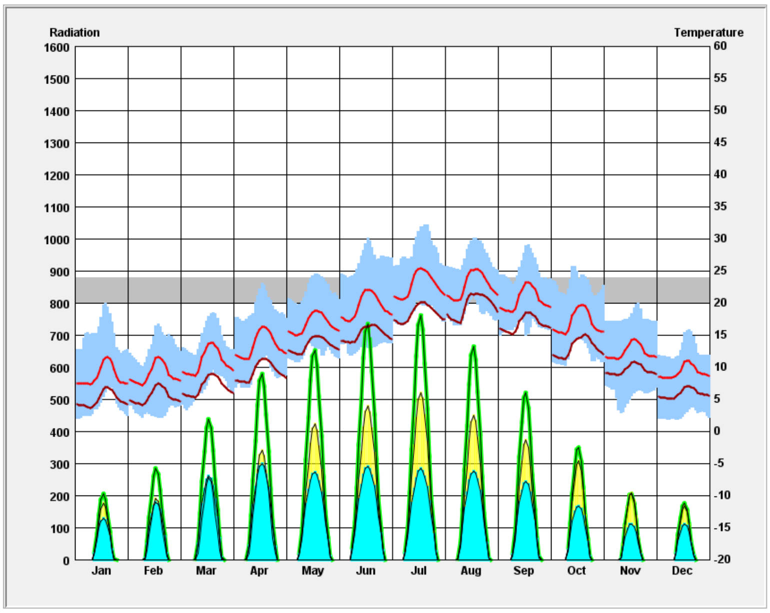

Figure 8. Monthly diurnal averages[8]

2.2.2. Winds

The analysis of the annual wind patterns indicates significant concern regarding wind conditions in this area. On average, wind duration is rather stable throughout the year, with velocities reaching maximum of 22 m/s. Notably, one of the peak months for wind velocity is May, during which maximum velocities overcome 22 m/s. Despite the potential challenges that strong winds may present, they can be exploited during the summer months to facilitate natural ventilation, thereby enhancing thermal comfort and improving indoor air quality.

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[8] Retrieved from Climate Consultant software

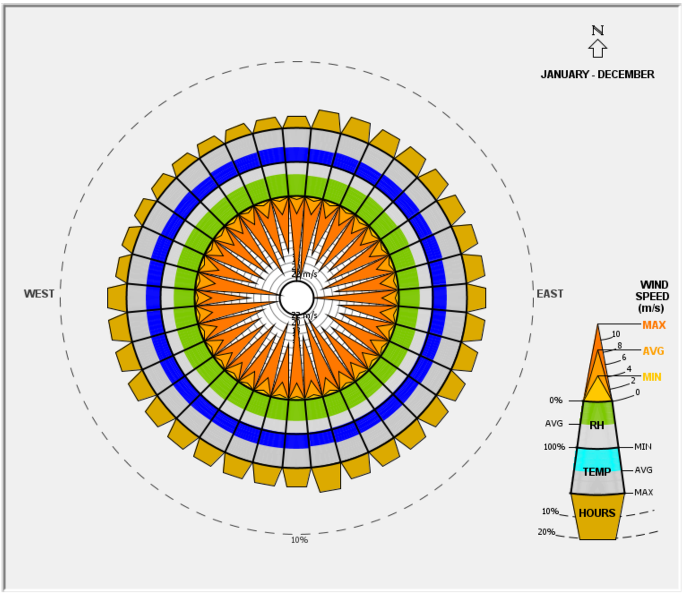

Figure 9. Annual wind chart[9]

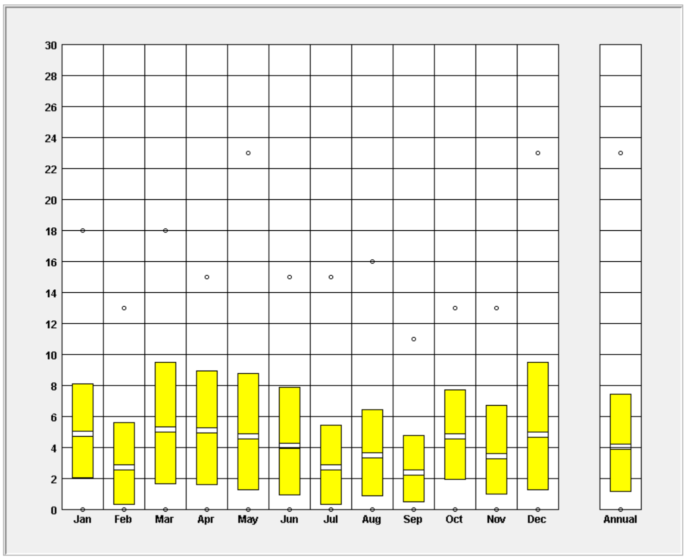

Figure 10. Wind velocity range[9]

2.2.3. Sun path

Sun path analysis can be conducted through either solar and shading chart. Aligned with the observations from the temperature chart, sunlight is crucial during cold months, whereas shading becomes essential during hot months. These concerns must be carefully integrated into the design process in order to optimize the utilization of winter sun rays for warmth during the colder months while also providing adequate shading to the building during warmer months. By strategically integrating these aspects into the design, it is feasible to

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[9] Retrieved from Climate Consultant software

achieve enhanced thermal comfort and energy efficiency throughout the year.

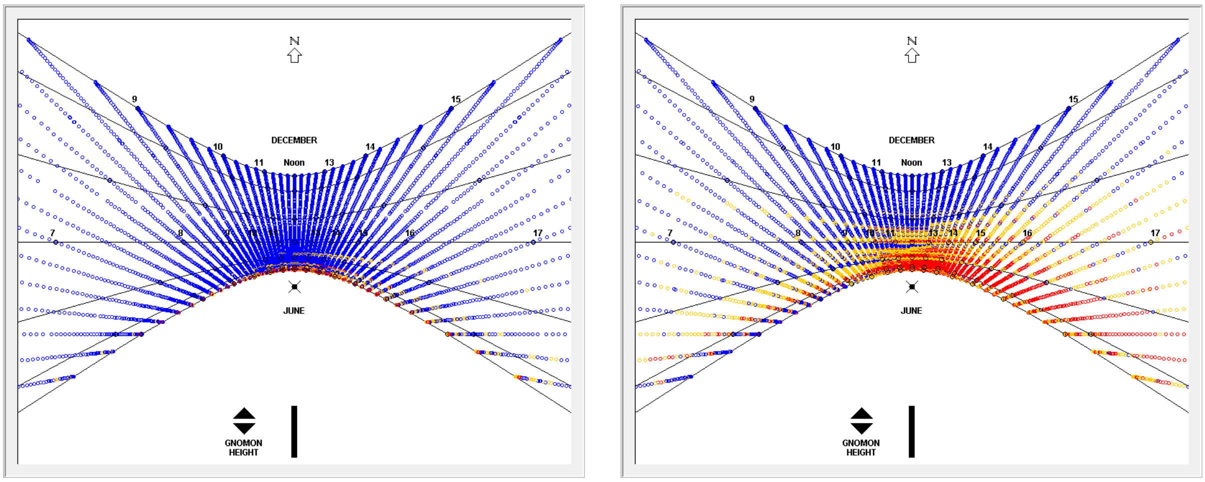

Figure 11. Sun charts - December to June and June to December[10]

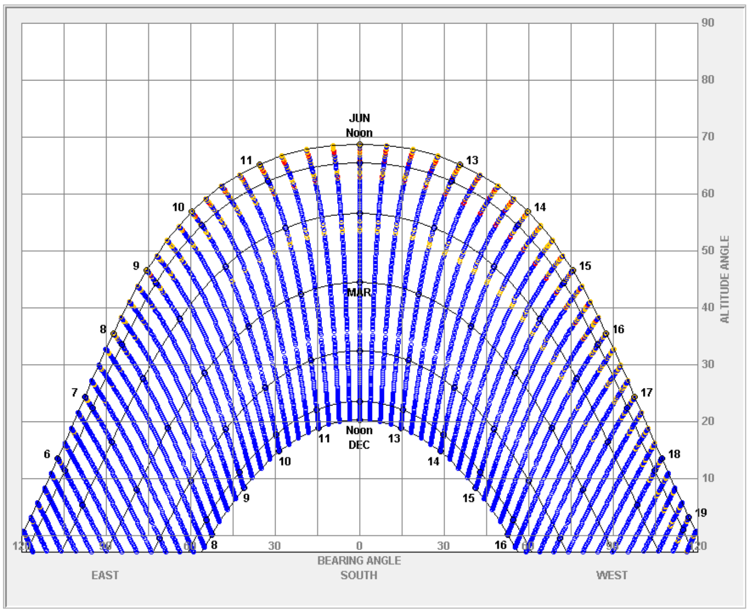

Figure 12. Sun shading chart - December to June[10]

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[10] Retrieved from Climate Consultant software

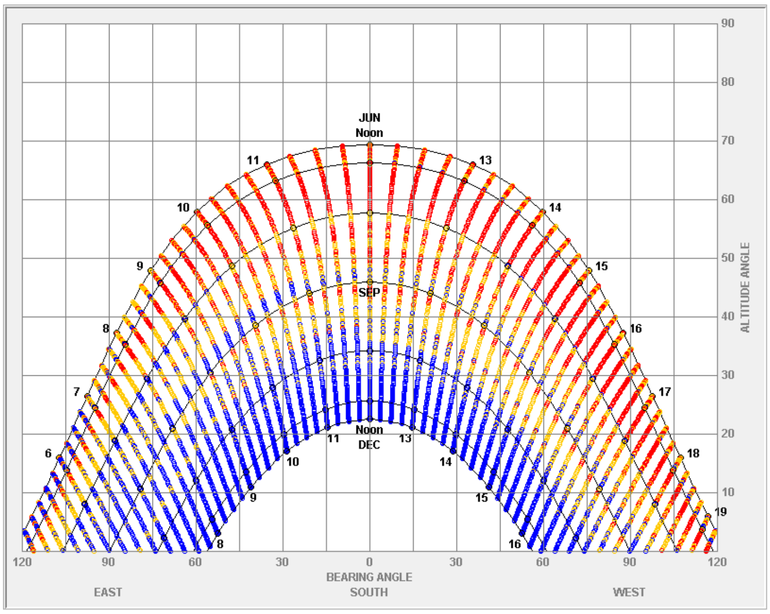

Figure 13. Sun shading chart - June to December[11]

2.2.4. Precipitation

Rainwater represents a crucial resource that can be harvested for both potable and non-potable uses, including cooking, drinking, bathing, and toilet flushing. Particularly in buildings equipped with green walls or roofs, rainwater can be utilized for plant irrigation, thereby promoting sustainable water usage practices. Harvesting rainwater also plays a significant role in reducing runoff volume during periods of heavy rainfall, consequently mitigating the risk of flooding and erosion. Both potable and non-potable uses of rainwater require some form of treatment before it can be safely utilized. Implementing rainwater harvesting systems helps to address increasing water demands, navigate water use restrictions, and adhere to new stormwater management regulations. Furthermore, it contributes to the growth of low-impact development buildings by promoting environmentally-friendly water management practices.

Prior to implementing a rainwater harvesting system, it is essential to estimate the amount of rainfall expected and the corresponding indoor water demand based on the building type. The effectiveness of such a system is directly influenced by factors such as the size and dimensions of the collector, which in turn depend on indoor water demand and precipitation levels. For instance, in the case study site, the peak precipitation occurs in October, with approximately 95mm of rainfall, whereas July experiences lower rainfall,

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[11] Retrieved from Climate Consultant software

around 16mm. Therefore, achieving an effective balance between months with high and low precipitation is crucial for the successful implementation of a rainwater harvesting system.

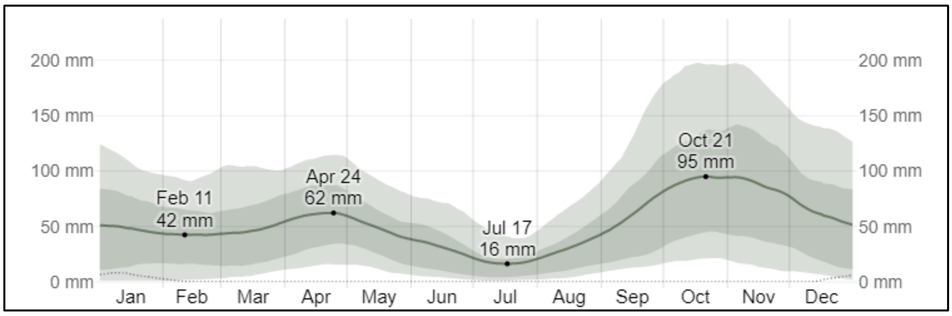

Figure 14. Average monthly rainfall[12]

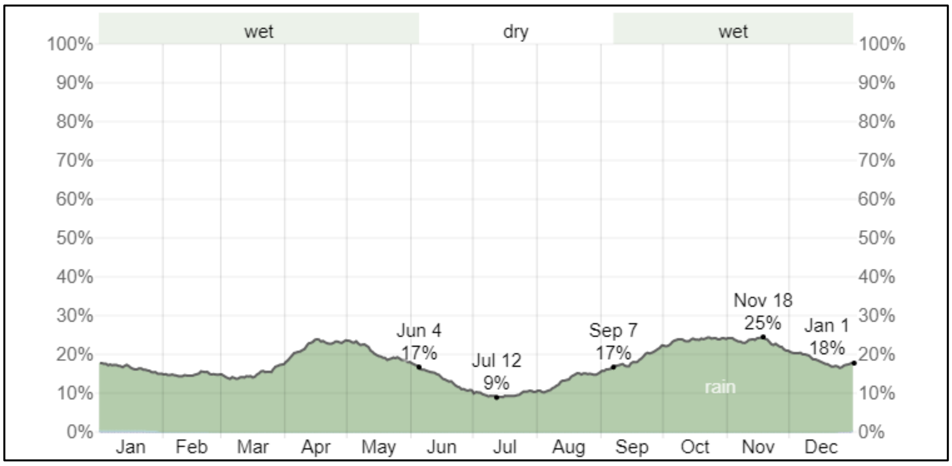

Figure 15. Daily chance of precipitation[12]

2.2.5. Design strategies

According to the analysis derived from the psychrometric chart, approximately 13.1% of the year provides occupants with a thermally comfortable environment within the microclimate of Albenga. However, to ensure occupant comfort during the colder seasons, heating is required for approximately 37% of the year. It is worth noting that relying on internal heat sources in the indoor environment, such as lighting, occupants' activities,

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[12] Retrieved from Climate Consultant software

electronic devices, and cooking, can contribute to maintaining thermal comfort for approximately 35% of the year.

Considering these factors, the significance of having a properly sealed and thoroughly insulated building cannot be overstated. Such measures are essential not only for minimizing heat loss during colder periods but also for optimizing energy efficiency and enhancing overall occupant comfort throughout the year. By effectively managing internal heat sources and implementing robust insulation measures, it becomes possible to create a consistently comfortable indoor environment while reducing reliance on external heating systems.

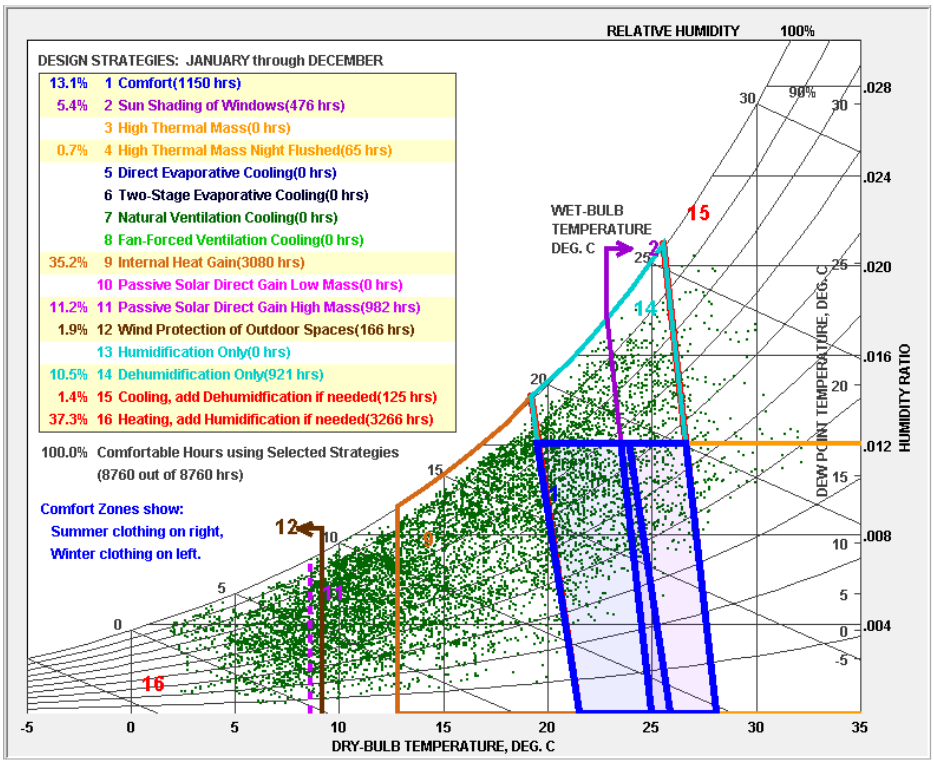

Figure 16. Psychrometric chart[13]

According to the climatic analysis performed, the site resulted being in climatic zone C.

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[13] Retrieved from Climate Consultant software

2.3. REGULATORY CONSTRAINTS

The design of a building must fulfil several legislative requirements concerning different fields of application.

The Ministerial Decree 18/12/1975 and the update of 13/09/1977 report technical standards for school buildings.

The President of the Republic Decree 380/1 is the Construction Standard Single Text.

The Law 11/01/1996, n. 23 reports standards for school buildings.

The Ministerial Decree 26/06/2015 prescribe thermal energy performance for heating and cooling.

3. DESIGN

3.1. MASTERPLAN

The design concept originated from an analysis of the existing structure of the barrack's dormitories. The barracks consist of six buildings arranged in a "U" shape, each surrounding a central courtyard. This layout served as the initial inspiration for shaping the school complex.

Figure 17. Project Masterplan

Building A features a symmetrical layout that mirrors the modular design characteristic of the barracks, comprising of two "U" shapes repeated and oriented towards the south.

Another significant consideration was to limit the vertical development of the building. Hence, the majority of the structure is situated at ground level, with only a portion extending to the central part of the building.

Building B and Building C are two-story structures elevated above ground level. They are detached from the main building and linked to it via covered walkways, ensuring sheltered passage between the building.

The symmetrical overall layout facilitated ease in design, and allows faster construction and realization.

One the primary considerations during the preliminary design phase was the consideration of climatic conditions. Specifically, the layout of Building A was designed to maximize natural ventilation by leveraging the prevailing wind direction from the south during the hot season.

Additionally, Buildings B and C, characterized by their nearly transparent envelope, are shielded from direct sunlight by the opaque south facade of Building A. Moreover, they are partially shaded by the first floor of Building A, further enhancing their thermal comfort.

3.2. DEFINITION OF INTENDED USES

Aligned with the goal of ensuring accessibility to the municipal community, the general layout of the school complex was designed to distinguish between spaces dedicated solely to educational activities and those available for broader community use. These spaces are accessible beyond traditional school hours.

To this end, the ground floor of Building A primarily serves educational purposes, housing classrooms, related services, and a mechanical room inaccessible to non-experts.

Conversely, the first floor serves a variety of purposes. It includes various laboratories accessible during both school hours and other times of the day, relaxation areas, meeting points for both students and the wider community, meeting rooms, quiet spaces suitable for collaborative work or individual study, and ICT laboratories available for use outside of school hours, providing access to technological resources.

Building B retains a learning focus, accommodating didactic laboratories. As it is separate from the central hub of the school complex, it can be accessed outside of traditional school hours by students seeking to enhance their learning through practical application.

Building C serves administrative purposes, housing professors' offices and archives. However, it also caters as a nexus for integration between the school and the municipality. On one hand, it features a café, acting as a social hub for daily city life, and on the other hand, it houses a library open to individuals of all ages seeking to pursue their interests and education.

3.3. DESIGNING A SCHOOL FOR THE FUTURE

New educational guidelines outlined in paragraph 1.3 served as the foundation for the interior design of the building.

During the design phase, emphasis was placed on integrating usability, aesthetic appeal, and functionality. Ensuring optimal learning conditions and safety, while also enhancing the building's aesthetic appeal and functionality, was a primary focus, drawing inspiration from the German model of education.

As previously discussed, the diverse range of social forms significantly contributes to educational objectives. This principle was put into practice by designing various spaces with differing sizes, purposes, and functions. These spaces not only provide additional room beyond traditional classrooms but also utilize the surrounding open areas effectively.

Paragraph 3.2 outlines the intended use for macro categories. These spaces offer excellent flexibility to meet the diverse needs of the learning environment. For instance, meeting rooms at first floor are ideal for situations where communication occurs from few to many (“Campfire”), as well as allowing for group work discussion and interaction (“Watering Hole”). Meanwhile, dedicated "Laboratories" in Building B allow students to engage in practical experiments and projects. Additionally, “Caves” are encouraged by the amount of open-air space available during warmer seasons, but also provided by silence rooms, library and relax areas. In this way every necessity of individuals attending the school are taken into account.

Moreover, it is essential for the school complex to perfectly integrate with the local community. To achieve this goal, significant effort was invested in establishing the school as a social and cultural hub, accessible and appealing to the entire community. Various strategies were considered during the design phase, including providing separate entrances to facilitate access to school activities beyond regular hours. Furthermore, the large open spaces were designed to be accessible to the local community, fostering social interaction and making the school a focal point within the municipality.

4. TECHNOLOGICAL DESIGN

During the development of the design concept, identifying the right technological choices was crucial, considering their significant impact on the sustainability, energy efficiency and overall functionality of the building. In this regard, traditional construction technologies were integrated with the latest trends in terms of materials selection, structural solutions and exploitation of renewable energies. Ensuring environmental, energy and economic sustainability, while providing rapid construction, recyclability of materials and components, high energy performance, use of renewable sources and ease of maintenance, was on stunning importance. It was required to integrate new solutions and technologies with the building's practical needs within its specific context in order to meet all these objectives.

4.1. STRUCTURAL LAYOUT

Two primary typologies are involved in the structural arrangement, which are differentiated based on the requirements of the associated areas and design decisions.

4.1.1. Reinforced concrete structure

The initial structural system under analysis refers to the arrangement of reinforced concrete pillars and beams, concerning the Building A, which specifically houses the primary didactic activities.

The structural grid is squared 5 meters by 5 meters, allowing for great freedom in arranging spaces.

One of the most significant factors was the design flexibility offered by reinforced concrete structures. Opting for this structural technology provides the possibility for addressing architectural and structural requirements with optimal efficiency.

Furthermore, safety emerges as a crucial point in the design of a school complex. In this regard, reinforced concrete structures offer superior fire resistance compared to alternatives such as steel. Additionally, concrete exhibits functional characteristics concerning resistance to weather conditions, such as rain, wind and earthquakes. At this purpose, the safety topic is joined by the easiness in maintenance of concrete, especially in the long term.

Sustainability considerations concern various spheres of application. In opting for a reinforced concrete structure, another significant factor was the associated cost-effectiveness. When considering the total life cycle cost, reinforced concrete proves to be highly cost-effective, especially over the long term.

Conversely, when considering sustainability strictly in terms of material life cycle, reinforced concrete may not be the most effective material. However, exploring the utilization of recycled materials acts in the direction of mitigating the material's impact.

Lastly, considering the need to reduce the reliance on mechanical systems for climate control, concrete proves efficacy in terms of acoustic and thermal insulation.

4.1.2. Steel structure

Building B and C have two different designated uses; however, they share similar requirements, which have led to a structural solution consisting of steel elements. Specifically, this solution comprises HEA 220 profiles as pillars and IPE 550 as primary beams.

Moreover, steel structures are employed in each pedestrian walkway connecting the various buildings of the complex. In this scenario, the structural arrangement consists of HEA 160 profiles as pillars and IPE 270 as beams.

The primary factor in selecting steel arrangement was the need to provide spaces free from structural elements. Steel enables the construction of thinner and lighter structures due to its high strength-to-weight ratio, thereby allowing for greater flexibility in design and facilitating future modifications or expansions with minimal disruption.

Another significant consideration regarding the choice of steel structure is its potential for off-site prefabrication and on-site assembly, maximizing the use of dry constructions. This approach minimizes the permanent impact on the surrounding territory and reduces construction time.

Additionally, while steel may be initially more expensive, the faster construction process results in savings in terms of labour, transportation and erection expenses.

In terms of sustainability, steel offers advantages throughout its life cycle. From production, which has become increasingly energy and resource-efficient, to its end-of-life, being 100% recyclable.

Lastly, the topic of natural light was crucial for both Building B and Building C as they house spaces where good lighting is of major importance. In this regard, steel structures effectively complement curtain walls.

4.1.3. Slab

Focusing on Building A, the internal horizontal partitions were designed to consist of ribbed slabs, precisely hollow-core slabs. The potential of combining lightweight with good structural strength was the key factor in selecting this structural solution.

Moreover, ribbed slabs are manufactured off-site under controlled conditions, resulting in higher efficiency in terms of construction times and labour costs.

Ribbed slabs exploit the arrangement of beams and voids to maximize structural efficiency, reducing the amount of material required to achieve the same strength as a traditional slab and minimizing waste. The voids reduce the overall weight of the slab without affecting its load-bearing capacity. This approach allows for minimizing the use of traditional concrete structures.

4.2. BUILDING ENVELOPE

The horizontal and vertical partitions that separate the internal environment from the external surroundings are referred to as the "building envelope".

The primary purpose of the building envelope is to regulate thermal insulation, minimizing heat loss in colder climates and heat gain in warmer ones. Additionally, it is essential to prevent uncontrolled airflow and the infiltration of external agents such as rainwater and humidity.

The building envelope also plays a fundamental role in acoustic insulation, particularly in environments dedicated to learning.

Eventually, the envelope defines the architectural character and appearance of the building, contributing to its visual appeal and overall identity.

4.2.1. External walls

The primary objective in designing the external partition was to ensure the highest level of thermal insulation while also prioritizing ease and speed of construction. To effectively achieve this combination, it was opted to design the external wall using various types of plasterboard, with air cavities or insulation layers in between. The finishing is made of bamboo tails anchored to the final plasterboard. The overall wall stratigraphy is visible in Figure 18.

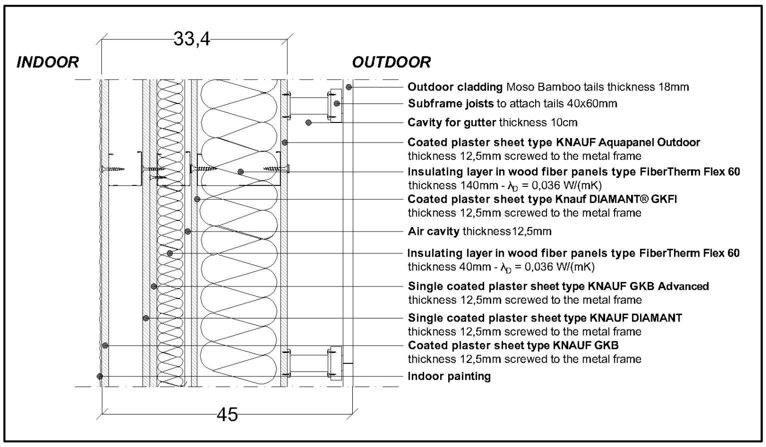

Figure 18. External wall stratigraphy

Further insights on technological solutions will follow in the next paragraphs.

4.2.2. Roof

In addition to fulfilling the same functions of the external vertical partitions, roofs assume supplementary roles concerning precipitation management. The selection between a flat or pitched roof significantly influences its behaviour while also offering an opportunity for efficient space utilization.

The initial consideration pertains to flat roofs, which are prevalent in both Building B and C, as well as comprising a significant portion of Building A. This decision primarily revolves around the potential to create rooftop gardens, thereby reclaiming part of the soil footprint occupied by the construction. This approach aids in mitigating the Urban Heat Island effect, as plants absorb and dissipate heat from waterproof surfaces, resulting in a decrease in average temperature. Additionally, green roofs enhance air quality by absorbing CO_2 and other pollutants.

Furthermore, the impact of green roofs on indoor bioclimatic conditions is well-documented. They improve thermal insulation during both cold and hot seasons, reducing overheating in summer and retaining heat in winter.

Green roofs also absorb rainwater, reducing the load on drainage systems and mitigating flooding, which is a significant concern in the Liguria region, particularly given the area's proximity to the river.

Given these advantages, green roofs cover almost the entire surface of the buildings.

However, a central portion of Building A's roof has a slope to directly expose it to sunlight, facilitating the installation of photovoltaic panels, a topic to be explored further in subsequent paragraphs.

In Figure 19, the stratigraphy of the flat roof is depicted.

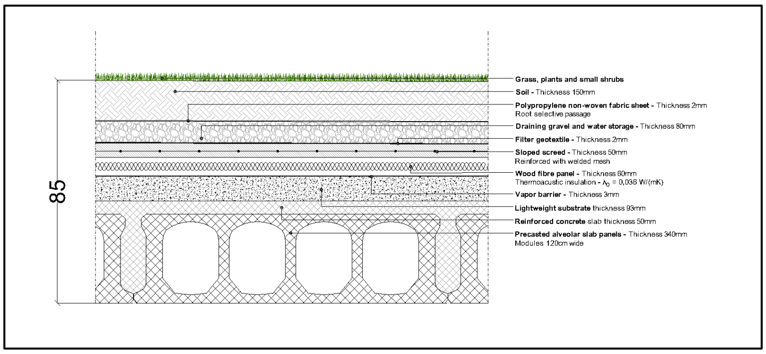

Figure 19. Flat roof stratigraphy

In addition to the structural features of the roof described in paragraph 4.1.3, the upper layers serve to properly insulate the building envelope, through a 6-centimetres layer of wood fibre panel, followed by the prevention of infiltration via vapour barrier, and ultimately supporting the above layers with a screed reinforced with welded mesh.

Before discussing the features of the designed green roof, it is imperative to delineate a fundamental distinction between extensive and intensive green roofs.

An extensive green roof is crafted to be lightweight, thereby minimizing the load on the supporting structure. Typically, it necessitates 8-15 centimetres of soil to accommodate grass and plants. Extensive green roofs are predominantly selected for large areas and are not intended for pedestrian access except for maintenance purposes, which are however needed less frequently.

Conversely, intensive green roofs feature a thicker soil layer, which provides more opportunities for diverse plant life and landscaping. However, this thicker soil layer necessitates more frequent and rigorous maintenance to sustain optimal health and appearance. Additionally, due to the heavier load they impose, intensive green roofs require more robust support structures.

Given the requirement to cover an extensive surface area not designated for pedestrian use, the extensive green roof solution has proven to be more efficacious.

For the implementation of an extensive green roof, a substrate package of 20-30 centimetres is necessary to create a suitable environment for the growth of grass, plants, and small shrubs. This package consists of a geotextile filter, which retains soil particles and debris, followed by a drainage layer containing gravel and soil conducive to root growth.

Additional insights into technological solutions will be provided in the following paragraphs.

4.2.3. Slab on the ground

The ground floor slab serves as a boundary between the indoor and outdoor environments, differing from walls or roofs due to direct contact with the soil. Consequently, the characteristics of a slab on the ground vary slightly.

One shared characteristic across all parts of the building envelope is thermal insulation. Proper protection of the ground slab is essential to prevent heat loss through the terrain, ensuring indoor thermal comfort. Simultaneously, effective acoustic insulation is crucial to minimize noise transmission from the ground or other external sources.

Additionally, waterproofing is of utmost importance. High water resistance properties are essential for the ground floor slab to prevent rising damp or infiltration from the ground. Thus, adequate ventilation beneath the slab assists in controlling humidity and thereby reduces the risk of mould or condensation.

Considering the above-mentioned factors, technological choices concerning the ground floor slab are depicted in Figure 20.

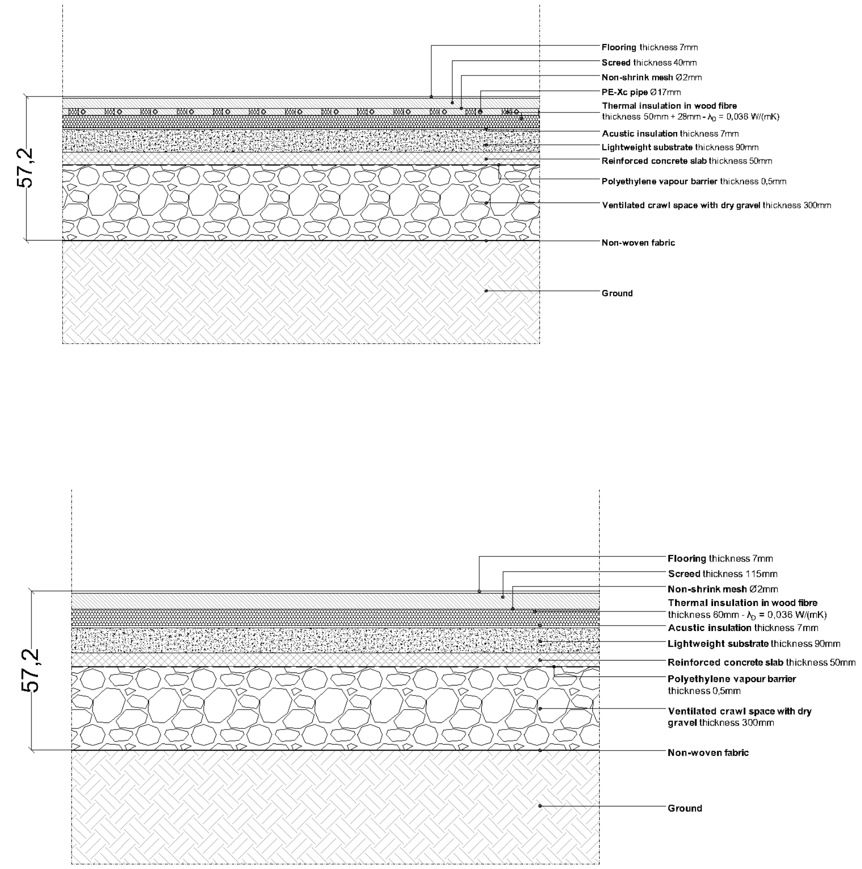

Figure 20. Ground floor slab stratigraphy

Directly in contact with the ground is a layer of non-woven fabric, acting as a barrier against humidity to prevent rising infiltration. The subsequent layer consists of a 30 centimetres thick ventilated crawl space filled with dry gravel, facilitating ventilation to minimize humidity beneath the slab. Additionally, a polyethylene vapor barrier prevents humidity infiltration, separating the ventilated crawl space from the structural component: a 5 centimetres thick reinforced concrete slab.

The above layers are integral to the finishings of the slab and will be discussed further in subsequent paragraphs.

4.3. VERTICAL PARTITIONS

4.3.1. Internal partitions

Internal vertical partitions optimize space efficiency by tailoring it to users' specific needs, facilitating activities without interference from adjacent spaces and ensuring proper acoustic insulation. Additionally, these partitions can be designed to provide thermal insulation, creating distinct indoor climates for each room, thereby reducing heat losses and enhancing energy efficiency.

Based on these considerations, two main distinctions were made regarding internal spaces. The primary consideration prioritizes acoustic insulation between classrooms to provide conducive learning environments, while the secondary consideration addresses varying thermal needs, recognizing that different spaces require different optimal temperatures. Thus, thermal insulation plays a central role in the design of these partitions. The design of vertical partitions, dividing classrooms and other spaces, heavily emphasizes these aspects.

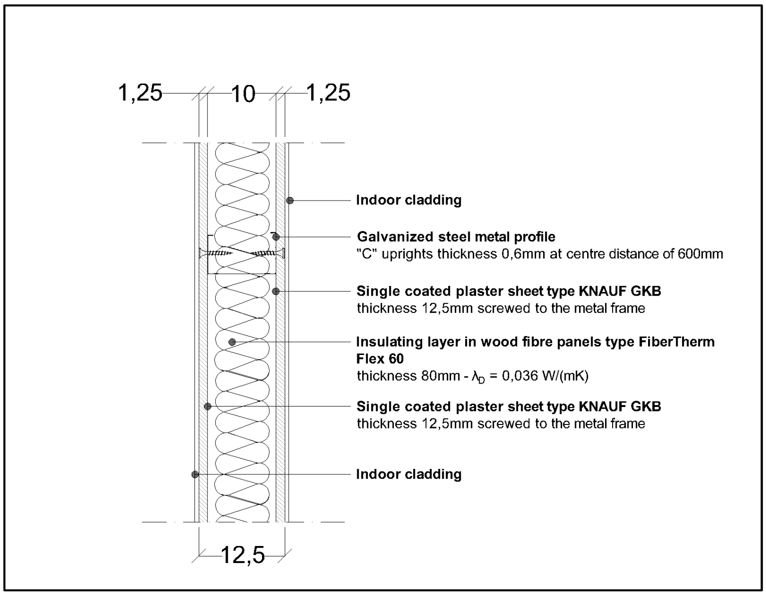

Figure 21. Vertical internal partition stratigraphy

Figure 21 illustrates the stratigraphy of these partitions, typically comprising two 7.5-centimeter-thick layers of wood fibre panels sandwiched between coated plasterboards on each side, ensuring both thermal and acoustic insulation.

This standardized layout, featuring sandwich panels with plasterboards containing insulating layers, is common across all internal vertical partition typologies. It enables dry construction, facilitating rapid and straightforward prefabrication off-site and allowing for easy modifications to the internal space layout throughout the building's lifespan.

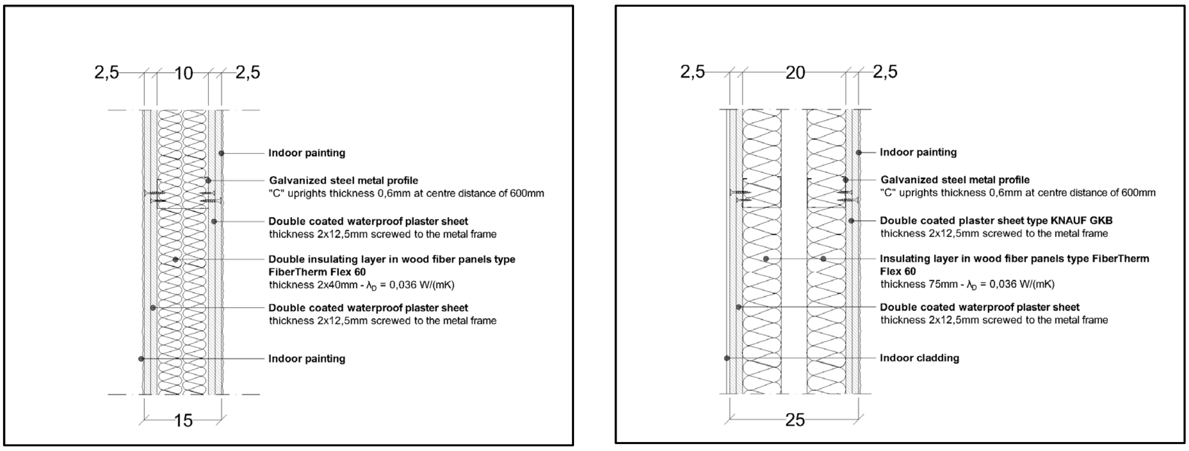

Figure 22. Vertical internal partitions stratigraphy

Figure 22 presents two additional partition typologies, where thermal and acoustic insulation are not as central, as these partitions primarily separate service areas from connective spaces. Instead, the focus is on minimizing thickness to avoid occupying excessive floor area.

4.4. THERMO-HYGROMETRIC VERIFICATIONS

Thermal energy performance for heating and cooling, to be verified through the **Reference Building Approach**.

The reference building is identical according to geometrical characteristic, orientation, territorial location, intended use and boundary conditions. Conversely, it refers to predetermined technical characteristics and energy parameters.

Ministerial Decree 26/06/2015 prescribes envelope parameters of the reference building and threshold values of thermal transmittance for building envelope components, which directly depends on climatic zone of the building under analysis.

Via "Involucro" spreadsheet, envelope parameters were calculated and consequently compared to the threshold values for climatic zone C.

4.4.1. Opaque vertical building envelope components

Opaque vertical components prescriptions are detailed in Table 1.

Climatic zone	U (W/m^{2}K)	
	2015	2019/2021
A and B	0,45	0,43
C	0,38	0,34
D	0,34	0,29
E	0,30	0,26
F	0,28	0,24

Table 1. Opaque vertical building envelope components' threshold values[14]

Furthermore, Table 2 presents the stratigraphy of vertical envelope components along with the resulting thermal transmittance.

Layers		d	ρ	μ	c	λ	R
int-ext		[cm]	[kg/m^3]	[-]	[J/kg°C]	[W/m°C]	[m^2°C/W]
Internal surface							0,13
I	Plaster board	1,25	665	4	1090	0,200	
II	Air cavity	6	1	1	1000		0,18
III	Plaster board	1,25	1040	4	1090	0,250	
IV	Plaster board	1,25	600	6	1090	0,190	
V	Thermal insulation	4	60	1	2100	0,036	
VI	Air cavity	1,25	1	1	1000	0,260	
VII	Plaster board	1,25	1040	4	1090	0,250	
VIII	Thermal insulation	14	60	1	2100	0,036	
IX	Plaster board	1,25	1150	6	1090	0,350	
External surface							0,04
Thermal transmittance (U)		0,177	W/(m^{2}K)				

Table 2. External wall stratigraphy and thermal transmittance calculation

It is evident that the parameters of the buildings meet the required threshold values.

The "Involucro" spreadsheet ultimately indicates that, given the thermal parameters and climatic zone, the designed opaque vertical building envelope components are not prone to surface and interstitial condensation.

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[14] Values provided by Ministerial Decree 26/06/2015

4.4.2. Opaque horizontal components – roofs and ceilings

Roofs and ceilings prescriptions are detailed in Table 3.

Climatic zone	U (W/m²K)	
	2015	2019/2021
A and B	0,38	0,35
C	0,36	0,33
D	0,30	0,26
E	0,25	0,22
F	0,23	0,20

Table 3. Roofs and ceilings' threshold values[15]

Furthermore, Table 4 presents the stratigraphy of roof components along with the resulting thermal transmittance.

Layers		d	ρ	μ	c	λ	R
int-ext		[cm]	[kg/m³]	[-]	[J/kg°C]	[W/m°C]	[m²°C/W]
Internal surface							0,10
I	Lightweight substrate	9	-	-	-	0,073	
II	Thermal insulation	6	60	1	2100	0,036	
III	Screed	5	2000	69	880	1,160	
IV	Draining layer	8	25	70	1339	0,111	
V	Soil	15	980	20	839	0,200	
External surface							0,04
Thermal transmittance (U)			0,290	W/(m²K)			

Table 4. Roof stratigraphy and thermal transmittance calculation

It is evident that the parameters of the buildings meet the required threshold values.

The "Involucro" spreadsheet ultimately indicates that, given the thermal parameters and climatic zone, the designed roof components are not prone to surface condensation.

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[15] Values provided by Ministerial Decree 26/06/2015

4.4.3. Opaque horizontal components – bottom floors

Bottom floors prescriptions are detailed in Table 5.

Climatic zone	U (W/m^{2}K)	
	2015	2019/2021
A and B	0,46	0,44
C	0,40	0,38
D	0,32	0,29
E	0,30	0,26
F	0,28	0,24

Table 5. Bottom floors' threshold values[16]

Furthermore, Table 6 presents the stratigraphy of bottom floor components along with the resulting thermal transmittance.

Layers		*d*	*ρ*	*μ*	*c*	*λ*	*R*
int-ext		[cm]	[kg/m^3]	[-]	[J/kg°C]	[W/m°C]	[m^2°C/W]
Internal surface							0,17
I	Ventilated crawl	30	280	5	920	0,090	
II	Slab	5	2000	69	880	1,160	
III	Lightweight substrate	9	-	-	-	0,073	
IV	Thermal insulation	5	60	1	2100	0,036	
V	Screed	4	2000	69	880	1,160	
VI	Flooring	0,7	-	-	-	1,000	
External surface							0,04
Thermal transmittance (U)			0,196	W/(m^{2}K)			

Table 6. Bottom floor stratigraphy and thermal transmittance calculation

It is evident that the parameters of the buildings meet the required threshold values.

The "Involucro" spreadsheet ultimately indicates that, given the thermal parameters and climatic zone, the designed bottom floors components are not prone to surface condensation.

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[16] Values provided by Ministerial Decree 26/06/2015

4.5. HORIZONTAL PARTITIONS

From a functional standpoint, horizontal internal partitions serve various purposes within the building. Thermal and acoustic insulation are pivotal considerations in this regard, as previously discussed, to create optimal conditions for each space according to its designated use.

Conversely, from a structural standpoint, internal slabs facilitate the even distribution of loads onto the underlying structural elements. The structural solution adopted is the hollow-core slab, as elaborated in paragraph 4.1.3.

To enhance the energy efficiency of the building, countertops are strategically placed to reduce internal height, thereby minimizing the reliance on mechanical systems for indoor heating or cooling.

The primary distinction here lies between heated and unheated spaces, with radiant floor heating being the chosen system.

A radiant floor heating system comprises a network of pipes or electric heating elements installed beneath the floor surface. These elements radiate heat upward, warming the floor, which in turn heats the space above it.

Radiant floor heating offers superior thermal comfort compared to traditional systems, distributing heat evenly across the entire floor surface and eliminating temperature fluctuations and cold spots.

Moreover, it can be more efficient than traditional air or water heating systems, operating at lower temperatures and thereby reducing heat losses and energy consumption. Additionally, it operates quietly, as it does not involve the use of fans or other noisy components, enhancing acoustic comfort, particularly in environments such as school complexes. Simultaneously radiant floor heating can contribute to a healthier environment suitable for people sensitive to allergies, reducing the circulation of dust and allergens, since they do not require air circulation.

Eventually, radiant floor heating can be powered by various energy sources, including geothermal heat pumps or solar thermal systems, further enhancing its sustainability and minimizing carbon emissions.

4.5.1. Heated spaces

Heated spaces involve classrooms, connective spaces, laboratories, and any area where users spend extended periods.

The flooring technology for heated spaces is presented in Figure 23.

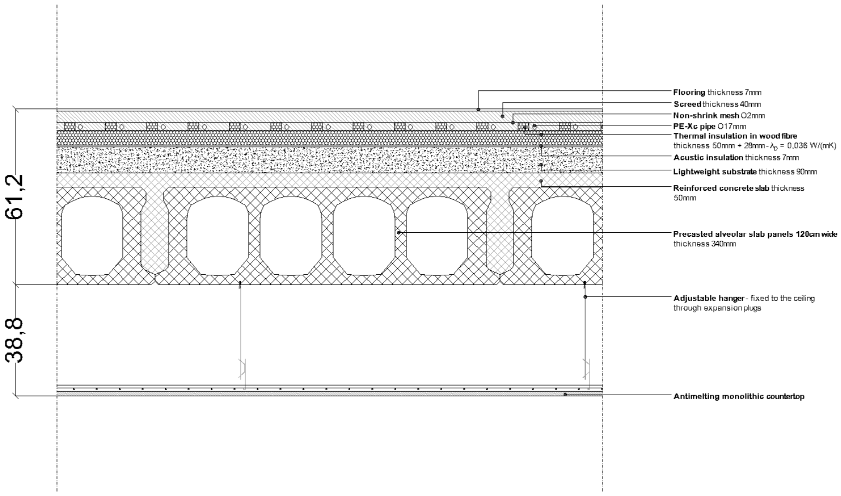

Figure 23. Heated spaces flooring system

Above the structural package of the slab, there is a lightweight substrate of 9 centimetres, providing the proper background for the decking, followed by acoustic insulation using an underlayment, and thermal insulation consisting of 5-centimeter-thick wood fibre panels. The upper layers comprise the heating piping system and a 4-centimeter-thick screed for flooring installation.

4.5.2. Unheated spaces

Conversely, unheated spaces mainly include services and mechanical rooms, where users do not spend extended periods.

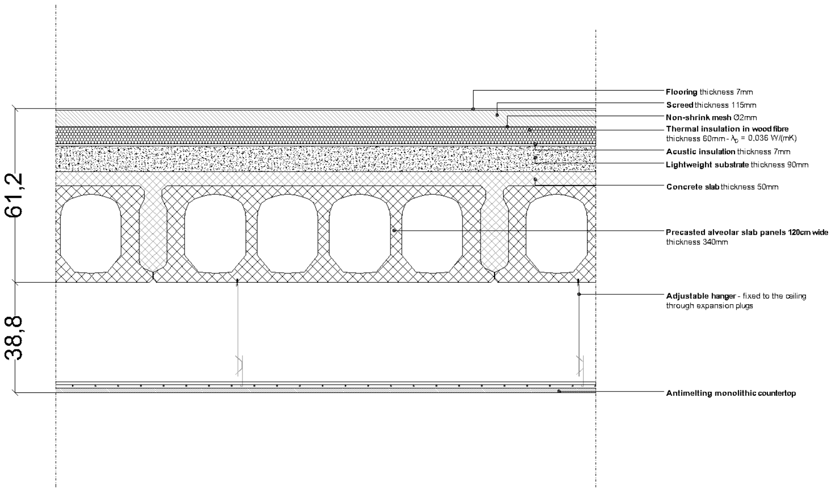

Figure 24. Unheated spaces flooring system

The flooring system stratigraphy for unheated spaces is illustrated in Figure 24. In contrast to the above-mentioned typology, the heating piping system is absent, allowing for a thicker layer of thermal insulation while maintaining adequate acoustic insulation.

4.6. MATERIALS SELECTION

Materials selection is a fundamental consideration aimed at minimizing the environmental impact of the building. The workflow should involve various aspects of materials' life cycle.

Sustainable materials are typically derived from renewable, recycled, or low-impact sources, reducing natural resource extraction and greenhouse gas emissions during production. This helps mitigate climate change and preserve the environment. Additionally, some conventional materials can release toxic substances into indoor air over time, compromising air quality and occupant health. Conversely, sustainable materials tend to be less toxic and can contribute to creating healthier and more comfortable indoor environments.

Furthermore, many sustainable materials exhibit superior properties, compared to traditional ones, in terms of thermal insulation, to cite an instance, leading to increased energy efficiency.

From an economic standpoint, while sustainable materials may initially occur in higher costs than traditional ones, in the long term they can lead to significant savings through reduced energy and maintenance expenses for buildings.

The end-of-life aspect of materials is another significant consideration, extending beyond the operational lifespan of buildings to include proper disposal methods.

4.6.1. Outdoor cladding

Given the aforementioned considerations, the goal of advancing toward a more sustainable materials selection has led to a preference for bamboo cladding over conventional wooden options.

Bamboo is regarded as a suitable building material due to its rapid growth and abundant availability, which does not contribute to deforestation as the plants regenerate after stem harvesting. However, bamboo requires additional protective treatments for outdoor use. Heat treatments and high-density compression processes enhance the properties of bamboo, making it a genuinely ecological and durable alternative to increasingly scarce tropical hardwoods.

Figure 25. Bamboo X-treme® Cladding system[17]

Bamboo provides numerous advantages throughout the construction process. The resulting product demonstrates exceptional hardness, durability, and stability over the building's lifespan. Installation is simplified thanks to the modular design of the boards, resulting in cost efficiency in transportation and time savings during setup. Additionally, ongoing savings can be achieved as bamboo cladding requires no maintenance, leading to reduced expenses during the activity period and in waste management.

Furthermore, bamboo products are confirmed to be CO_2 neutral over their entire life cycle, contributing to reducing the building's carbon footprint. Moreover, the final product is considered safe in terms of fire resistance without needing for expensive and environmentally damaging fire retardants, unlike other wood products.

Over time, like any wood species, bamboo cladding develops a beautiful, natural look after outdoor exposure, enhancing the building's elegance.

Appendix A and B refer to the Environmental Product Declaration and technical sheet about MOSO® Bamboo X-treme®. (MOSO Bamboo)

4.6.2. Thermal insulation

Another consideration on materials' sustainability was regarding the traditional synthetic insulation solutions, well-known as detrimental for their environmental

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[17] Retrieved from Moso Bamboo - «moso-bamboo.com»

impact, mainly concerning the non-renewable sources for their production, such as petroleum for expanded polystyrene, but also regarding difficulties in recycling.

Additionally, synthetic materials are often dangerous for human health, as they emit Volatile Organic Compounds (VOC).

Eventually, although designed to thermally insulate buildings, some synthetic insulation materials can lose their effectiveness over time, thus reducing the energy efficiency of buildings.

Conversely, natural insulation materials can afford the above-mentioned threads, being more sustainable.

The most efficient solution among the spectrum of possibilities was considered wood fibre, as it is derived from renewable sources, such as wood from sustainably managed forests or wood processing waste, subsequently, during production, wood fibre emits less carbon dioxide compared to petroleum-derived synthetic insulation materials. Additionally, wood is capable of absorbing and storing CO2 during its growth, thereby contributing to climate change mitigation and, eventually, wood fibre is biodegradable, meaning it can be easily disposed of sustainably at the end of its life cycle, reducing environmental pollution and occupying less space in landfills.

Figure 26. Wood fibre panel[18]

Moreover, natural insulation materials like wood fibre tend to be less prone to toxic emissions compared to synthetic materials. This makes them a better choice for indoor air quality and can contribute to creating healthier indoor environments.

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[18] Retrieved from BetonWood - «betonwood.com»

From a performance standpoint, often natural insulating materials provide high thermal insulation performance, comparable to those of synthetic materials and simultaneously have the ability to absorb and release moisture, helping to regulate humidity levels inside buildings and prevent the formation of mould.

Specifically, the product chosen for insulating the building is wood fibre panel, available on the market for different thicknesses, then flexible to adapt to many applications. It is produced with 90% of recycled materials from sustainable forests satisfying the Forest Stewardship Council® regulations. It is free from any toxic compound and certified by the most important quality certification marks.

The manufacturer declares a thermal conductivity coefficient λ_D of 0,036 W/(m·K), which is comparable to that of synthetic materials.

Appendix C and D refer to the Environmental Product Declaration and technical sheet about FiberTherm Flex 60 by BetonWood. (BetonWood)

4.7. RENEWABLE ENERGY

Implementing renewable energy in buildings is crucial for environmental and energy sustainability.

Buildings are major contributors to global greenhouse gas emissions due to energy consumption for heating, cooling, lighting, and appliances. Introducing renewable energy sources like solar, wind, and water can effectively mitigate these emissions, leading to cost savings and enhancing building self-sufficiency. Shifting away from non-renewable sources also reduces dependence on energy price fluctuations and mitigates the impact of extreme weather events that interrupt energy supply.

Ultimately, reducing reliance on fossil fuels for energy production decreases local air pollution, improving air quality and reducing associated health risks.

4.7.1. Photovoltaic panels

Photovoltaic panels are devices designed to convert sunlight into usable electrical energy. Composed of photovoltaic cells typically made of silicon, they absorb sunlight photons and convert them into electrons through the photovoltaic effect, directly converting light energy into electrical energy. Utilizing solar energy, which is free and abundant, reduces greenhouse gas emissions, thus mitigating climate change. Additionally, reducing reliance on traditional electricity sources can lower long-term energy costs.

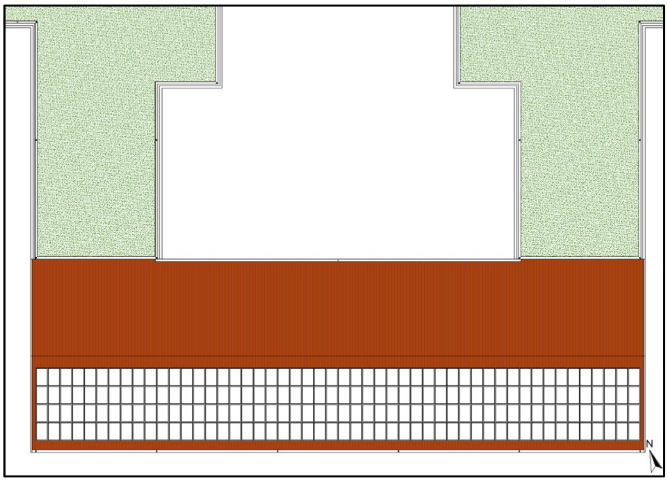

Figure 27. Photovoltaic panels installation

Photovoltaic panels provide green energy for various building needs, including lighting, appliances, and heating systems. The interaction between photovoltaic panels and radiant floor heating systems will be discussed further in paragraph 4.8.1.

4.8. INDOOR CLIMATE CONTROL

Indoor climate control cannot be separated from mechanical systems, what makes the difference is the origin of the energy used to power them.

This chapter presents and analyse HVAC systems adopted for the energy control of the school complex.

4.8.1. Heating system

The heating system, as previously mentioned, relies on radiant floor heating system powered by photovoltaic panels, which capture solar energy and convert it into electrical energy.

The electrical energy produced by the photovoltaic panels is then converted from direct current (DC) to alternating current (AC) by an inverter, necessary for powering the heating system, heat recovery unit, and other building appliances.

Subsequently, the electrical energy powers a heat pump, which through a thermodynamic cycle, extracts heat from the external environment and transfers it to the circulating liquid in the heating system. Integrated within the system is a heat recovery unit, which captures heat from exhaust air, transferring it to incoming fresh air to preheat it before entering the building. This process minimizes energy waste and enhances overall energy efficiency.

The heated liquid is then circulated through underground pipes or embedded within the building's floor, evenly and efficiently transmitting heat to warm up the floor. A temperature control system regulates the amount of heat transmitted to the radiant floor based on the building's requirements and occupants' preferences, achievable through local thermostats or a centralized control system.

Once the heat is transferred to the floor, warming the building's spaces, the cooled liquid returns to the heat pump to be reheated and recycled within the system.

This integrated system offers the benefits of clean and renewable energy from the sun, efficient heat recovery, uniform and comfortable space heating, and potentially reduced long-term energy costs. However, it necessitates an initial investment for the installation of photovoltaic panels, heat recovery unit, and radiant heating system, with effectiveness contingent on sunlight availability and local climate conditions.

4.8.2. Ventilation system

Based on the climatic analysis outlined in paragraph 2.2.2, a hybrid ventilation system was devised, integrating both natural and mechanical ventilation methods.

Given the predominant airflow from the south in the region, natural ventilation can be leveraged during warm seasons to cool indoor spaces through strategically positioned adjustable openings. These openings may feature automated or manual controls to manage airflow based on external and internal conditions.

Additionally, the system incorporates mechanical components to ensure consistent and efficient ventilation when outdoor conditions are not optimal or when increased air circulation is required. The mechanical ventilation can be powered by renewable energy sources such as photovoltaic panels, thereby reducing the overall environmental impact of the system.

Moreover, the system may integrate a heat recovery device to enhance energy efficiency. This device extracts heat from indoor exhaust air and transfers it to fresh outdoor air before entering indoor spaces, minimizing the need for additional heating or cooling and resulting in significant energy savings. An automated control system constantly monitors indoor and outdoor environmental conditions, adjusting ventilation accordingly to maintain indoor air quality and optimize energy efficiency. This can be done through temperature, humidity, and air quality sensors, along with intelligent algorithms that determine the best combination of natural and mechanical ventilation at any given time.

In conclusion, a hybrid ventilation system combining natural and sustainable mechanical ventilation methods can deliver a comfortable and healthy indoor environment while mitigating environmental impact and reducing overall energy consumption.

4.8.3. Sun radiation control

Solar energy can be even exploited without relying on mechanical systems. An example of this is the integration of adjustable sun shadings with windows. This method allows for the reduction of indoor overheating during warm seasons and the utilization of solar radiation for heating internal spaces through the adjustment of sun shadings.

This strategy gains further significance when considering the abundance of transparent components in Buildings B and C, enabling the maximization of their potential.

5. POTENTIAL FUTURE DEVELOPMENTS

The chapter concerning potential future developments incorporates several in-depth analyses and strategies that were not explored during the project's development phase. Should these be taken into consideration, the design could be enhanced in numerous aspects.

5.1. DESIGN DEEPENING

The design focus of the school complex primarily centred on Building A, with partial attention given to Buildings B and C. One avenue for future development involves deeper investigating the design aspects of Buildings B and C, considering technological solutions of steel structures and occasional enhancements to their conceptual designs.

Additionally, the competition notice stipulated the need for two gyms and an auditorium. Therefore, comprehensive design considerations for these facilities are warranted, taking into account their relationship with Buildings A, B, and C.

Moreover, there is potential to elevate the level of detail pertaining to Building A, further enhancing its performance and functionality. A deeper analysis of the spatial arrangement within the building, as well as the selection of furniture, could better reflect the principles outlined in paragraph 1.3, concerning new school guidelines. For instance, employing movable partitions between classrooms could expand the space depending on learning needs. Flexible furniture designs could allow for the transformation of spaces based on classroom activities. Additionally, involving future users, such as students and professors, in the design phase could ensure that their needs are adequately addressed.

Furthermore, a detailed analysis of HVAC systems is necessary to devise the optimal solution for the case study, necessitating precise calculations.

5.2. IMPROVED TECHNOLOGICAL SOLUTIONS

From another perspective, the performance of a building is heavily influenced by its technological design, which encompasses various aspects.

In terms of sustainability, traditional reinforced concrete structures may not be the most optimal solution. A potential improvement for the project could involve minimizing the use of concrete in favour of dry constructions, such as steel or wooden structures. These alternatives offer advantages such as faster and easier construction, thanks to prefabrication, as well as simplified maintenance and control. Additionally, they allow for easier modifications to the building layout and disposal at the end of its life cycle.

Transitioning from structural to thermal considerations, deeper exploration of materials and their potential applications could significantly enhance the efficiency of the building envelope. One viable solution involves filling the voids in ribbed slabs with insulating materials. This approach not only has the potential to reduce slab thickness but also to maintain or even enhance thermal properties.

Furthermore, a deeper analysis of material selection could result in the incorporation of more sustainable options without compromising the building's performance.

5.3. RENEWABLE ENERGY EXPLOITATION

The utilization of renewable energy in the project's design primarily involves the installation of photovoltaic panels. However, this strategy can be enhanced through a more comprehensive analysis of the building's electrical energy requirements to optimize the design of the installation.

Furthermore, considering another natural resource, rainwater, an analysis of its potential exploitation is necessary, particularly given the extensive green roofs designed for the building. Rainwater harvesting is crucial, aiming to minimize the impact on available water resources while simultaneously mitigating natural hazards such as floods, which are prevalent and dangerous in the Liguria region.

6. CONCLUSION

The design of a new school complex in Albenga aimed to establish a centralized hub for secondary education in the municipality. Currently, secondary high school facilities are fragmented across various complexes housed in ancient buildings, which are inadequate for modern learning environments.

Central to the design concept was the notion of the school as a civic centre, intended to appeal to the entire community. Sustainable construction principles guided the project's conception and design. Extensive consideration was paid to materials, technological solutions and energy efficiency to achieve a holistic approach.

Moreover, the project emphasized the necessity of rethinking teaching and learning strategies to ensure the school provides maximum functionality and adaptability to future users. This aspect proved to be particularly challenging, requiring a paradigm shift in educational practices.

One limitation of the design lies in the actual efficiency of the created spaces, which must align with evolving learning needs and design standards. A more in-depth analysis focused on maximizing space effectiveness would be beneficial.

Another critical aspect to consider was the economic viability of the project. Initially, implementing the new design concept may involve higher costs compared to traditional methods. Overcoming this obstacle requires a cultural shift in how buildings and schools are conceived and constructed. While this may present challenges, it is an inevitable step forward.

APPENDIX

Appendix A: Environmental Product Declaration MOSO® Bamboo X-treme® Cladding

Appendix B: Technical sheet MOSO® Bamboo X-treme® Cladding

Appendix C: Environmental Product Declaration BetonWood FiberTherm

Appendix D: Technical sheet BetonWood FiberTherm Flex 60

Appendix E: Elaborated items list

Appendix F: Masterplan - Scale 1:500 – Code: TH_GEN_01

Appendix G: Ground floor plan - Scale: 1:200 – Code: TH_ARC_01

Appendix H: First floor plan - Scale: 1:200 – Code: TH_ARC_02

Appendix I: Roof level plan - Scale: 1:200 – Code: TH_ARC_03

Appendix J: Elevations and Sections - Scale: 1:200 – Code: TH_ARC_04

Appendix K: Ground floor plan extract - Scale: 1:50 – Code: TH_ARC_05

Appendix L: Roof level plan extract - Scale: 1:50 – Code: TH_ARC_06

Appendix M: South elevation extract - Scale: 1:50 – Code: TH_ARC_07

Appendix N: Sections extracts - Scale: 1:50 – Code: TH_ARC_08

Appendix O: Stratigraphy and Construction nodes - Scale: 1:10 / 1:20 – Code: TH_ARC_09

FIGURES INDEX

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