6 · 1 | JUNE 2021

VITRUVIO

International Journal of
Architectural Technology and Sustainability

CIRCULAR ARCHITECTURE

Intervew to **BENEDETTA TAGLIABUE**

Vitruvio | International Journal of Architectural Technology and Sustainability | Research Journal Volume 6 · Issue 1 |
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Editorial

The contemporary scenario gives an increasingly higher complexity to the project of the built environment, determined by the quantity of factors involved and by the crisis that afflict them. Architecture has always followed the evolution of contexts and people, but today it is called upon to absorb radical changes that do not only concern formal or functional aspects but the survival of the planet and of men. If *firmitas* remains an invariable factor, even if it acquires complexity for the risks given by natural disasters, *utilitas* and *venustas* are destined to broaden their meanings. In fact, today the usefulness of a building is not only directly proportional to the possibilities of using it immediately but also compared to the possibilities that it can offer in the future (considering the conditions of the economic and health crisis). The concept of beauty of architecture has also overcome formal issues to be realized through the harmony between building systems, natural cycles of ecosystems and the quality of human life. It is no longer enough giving or giving back architectural quality to the building but it is urgent to seek a 360 ° quality, reconsidering the relationship between nature and buildings. The current reality configures particularly articulated demand frameworks, to whom rather than deciding if to demolish, transform or preserve we have to 'design' sustainable development processes of building systems and contexts as a whole. In the design activity, besides having to consider with particular attention requirements such as adaptability and flexibility because they are fundamental to prolong the life of buildings, it is necessary to bring the concepts of reuse and recycle back to the works to be carried out (both for new and existing buildings). Therefore the project can no longer only respond to the intervention needs of the present but must provide a predisposition to the evolution processes to satisfy future needs. Architecture should not only be built to become a real estate but it must also be built to externalize the character of a "built organism" and combine with natural cycles. The material-constructive choices should also consider among the available resources, those that can give not only excellent technical results but also advantages for people and for the planet. In this direction, the problems resolution can become the trigger for sustainable development processes if it is possible "to put into operation" the resilience capacities of places and individuals.

The writings in this issue of Vitruvio (*Circular construction, technology and architecture*,) decline in different directions the need to find new and shared design approaches, dictated by the just described scenario. The issue of circularity is faced, both in material terms (products and technical solutions) and in immaterial terms (performance of the spaces), at different scales and contexts.

Reflections are proposed on the relationship between the sustainability of the built environment and the ability of building systems to meet evolving needs. The circularity of the building is also addressed, presenting patented technical solutions able to simplify and speed up assembly and disassembly operations, to promote systems that can be reused and change location, with particular reference to emergency situations or the living needs. With this in mind, the project of adaptability becomes the key for defining and implementing resilient solutions. The articles also offer a critical reading of the (linear) architecture built before the development of the circularity concepts, to focus on the actions necessary to achieve a performance adjustment of public housing. Still with reference to this type of building, reflections are developed and studies are presented on the theme of regeneration aimed at achieving adaptive solutions to the scales of individual environmental units, accommodations, buildings and public spaces. Then they present material-construction solutions oriented towards circularity that is to trigger development processes through a project aimed at sustainability, adaptability, disassembly and recycling. Characteristics of sustainability are also found in some examples of traditional Turkish architecture which reveal excellent functioning in terms of comfort (temperature, ventilation, natural lighting) with consequent minimum energy consumption. For these buildings, analyses and developments are presented to re-propose the principles of sustainability in a new circular architecture. Another central issue of circular architecture that is dealt for the abandoned buildings and networks (as a result of processes of deindustrialisation), such as the disused railway heritage. Building reuse therefore becomes an important issue and acquires new roles as it allows "on standby" resources to be put back into operation and to design architectures that hopefully should never go "on standby».

The articles contained in this issue bring out various aspects and lines of research that can be further investigated and expanded to promote a complete development of the circular architecture concept.

Donatella Radogna

Quercus Cerris Pollino National Park (Basilicata, Italy)
The great heritage of hardwood *Quercus cerris* woods of Basilicata deserves to be enhanced, from a cradle-to-cradle point of view, to become a powerful factor for sustainable socio-economic development.

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The circular design for a school in conditioned *Quercus cerris* hardwood glulam

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Abstract: The *Design for Sustainability* of building processes and products is closely connected to *Design for Adaptability,* to *Design for Disassembling* and *Design for Recycling,* in a global perspective of *Circular Economy* that has at his centre the enhancement of renewable resources in specific environmental contexts, economic, social and cultural. This contribution is part of a research aimed at validating experiences already made in the direction of pre-competitive development, also with the aim of patenting process and products, with a *Cerro Lucano supply chain* that could constitute an important environmental protection factor, for social equity and economic development. In a series of previous researches, the application of this new material was hypothesized both in the field of conservation and refurbishment of building heritage, and for new ways of designing new buildings, even of considerable height. In this contribution it refers to its application to the design of a new nZEB school complex in Rionero in Vulture (Potenza), according to the principles of circular design.

Keywords: circular economy; design for sustainability; design for adaptability; design for disassembling; design for recycling; *Quercus cerris* engineered wood.

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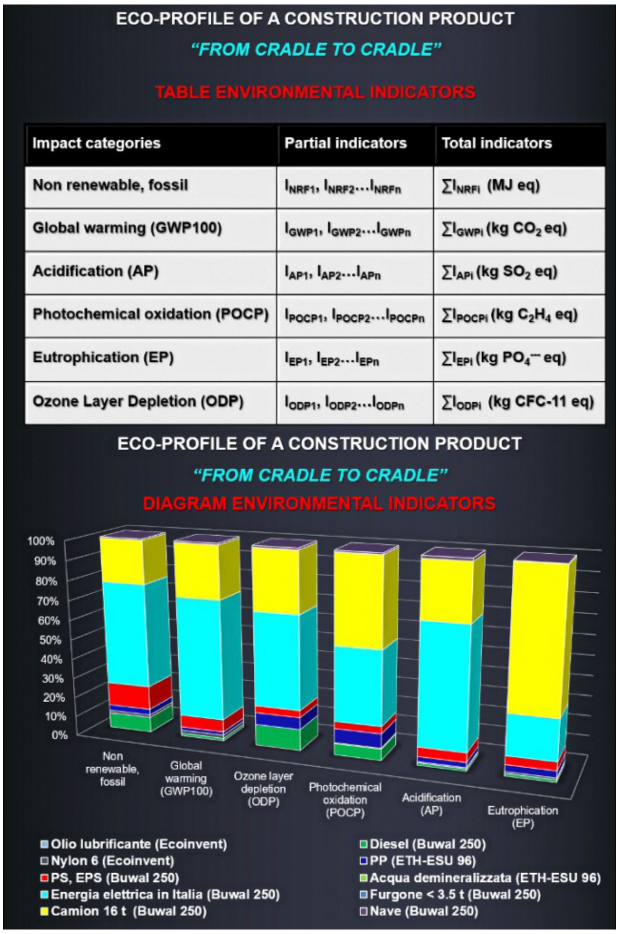
1. The enhancement of local resources as a fundamental element of a fully sustainable circular economy

Geldermans (2016) says that the quality of the recovered materials or the strategy adopted by *Design for Disassembly* (DfD) or *Design for Recycling* (DfR) is not so important, nor the fact that the components and materials are actually used, reused and recycled in the way expected, as well as an understanding of how such activities could actually generate positive environmental and social impacts and implications for the supply and value chain.

These activities are not related to the only stage of use of buildings, so the concept of environmental sustainability in the building sector must evaluate the environmental quality as a whole; namely it is related to meeting specific targets of environmental quality in relation to production, construction, operation and demolition activities of a building.

In the context of Circular Economy (Pearce & Turner, 1989; Jackson, 1993; Lovins & Hawken, 2010; Ellen MacArthur Foundation, 2013, 2017, 2019a, 2021; Arnette, Brewer & Choal, 2014; Ministère de l'Environnement, 2017; Raworth, 2018; Weetman, 2020; CICERONE 2020; PACE 2020; Finnish Innovation Fund SITRA, 2021), Circularity in construction is based, in one, on the resilience characteristics of the built environment and the multiple declinations and implications associated with environmentally responsible and sustainable building, in which the principles of circular building can be combined with the guidelines of *Design for Adaptability* (DfA) (Jockwer et al., 2021).

It is therefore necessary to start from the Cradle-to-Cradle (Stahel, 2019; Braungart & McDonough, 2009) LCA analysis, both on products and on technical elements (Fig. 1), exploring *Regenerative Design* (Lyle, 1994; Du Plessis & Cole, 2011), *Blue Economy* (Pauli, 2010) and *Circular Economy* (like above), to demonstrate the synergy between concepts of circularity and adaptability, technological modernity and innovation of architectural processes, which is not limited to the minimization of waste and the maximization of recycling, but which aims at an idea of Integrated Sustainability (Fig. 2) and absolute levels of energy efficiency.



ECO-PROFILE OF A CONSTRUCTION PRODUCT
"FROM CRADLE TO CRADLE"
TABLE ENVIRONMENTAL INDICATORS

Impact categories	Partial indicators	Total indicators
Non renewable, fossil	$I_{NRF1}, I_{NRF2}...I_{NRFn}$	$\sum I_{NRFi}$ (MJ eq)
Global warming (GWP100)	$I_{GWP1}, I_{GWP2}...I_{GWPn}$	$\sum I_{GWPi}$ (kg CO_2 eq)
Acidification (AP)	$I_{AP1}, I_{AP2}...I_{APn}$	$\sum I_{APi}$ (kg SO_2 eq)
Photochemical oxidation (POCP)	$I_{POCP1}, I_{POCP2}...I_{POCPn}$	$\sum I_{POCPi}$ (kg C_2H_4 eq)
Eutrophication (EP)	$I_{EP1}, I_{EP2}...I_{EPn}$	$\sum I_{EPi}$ (kg PO_4^{---} eq)
Ozone Layer Depletion (ODP)	$I_{ODP1}, I_{ODP2}...I_{ODPn}$	$\sum I_{ODPi}$ (kg CFC-11 eq)

ECO-PROFILE OF A CONSTRUCTION PRODUCT
"FROM CRADLE TO CRADLE"
DIAGRAM ENVIRONMENTAL INDICATORS

Figure 1 | Table and diagram of environmental indicator, referring to an example of eco-profile of a construction product in a Cradle-to-Cradle LCA analysis, performed with software EABM (P-product and TE-technical element), developed by the first two authors (Local Research, La.Te.C., Construction Technology Laboratory, 2012).

In this cultural horizon, the project proposed by the first two authors is set to enhance a large renewable forest resource in Basilicata, up to now little or not at all put in value. Basilicata hosts about 40% of the Italian hardwood heritage. It is about 4 million cubic meters of oak trees, *Quercus pubescens*, but above all *Quercus cerris*, planted in the early decades of the 20th century to serve as railway sleepers, which remained unused with the introduction of pre-stressed reinforced concrete sleepers. They must be cut to promote good health and the renewal of the woods. The new annual production is around 225,000 cubic meters (Local Research, 2003).

Almost all of the forests are regional or municipal property. Today, this large renewable resource is used only as firewood, and only imported woods are processed in Basilicata.

If we did not work for the optimal use of this "green resource", we would give up on creation of a very high added value, which could instead be achieved through the industrial development of a thermo-hygrometric conditioning protocol of *Quercus cerris*, which was developed by the first two authors of this contribution, as part

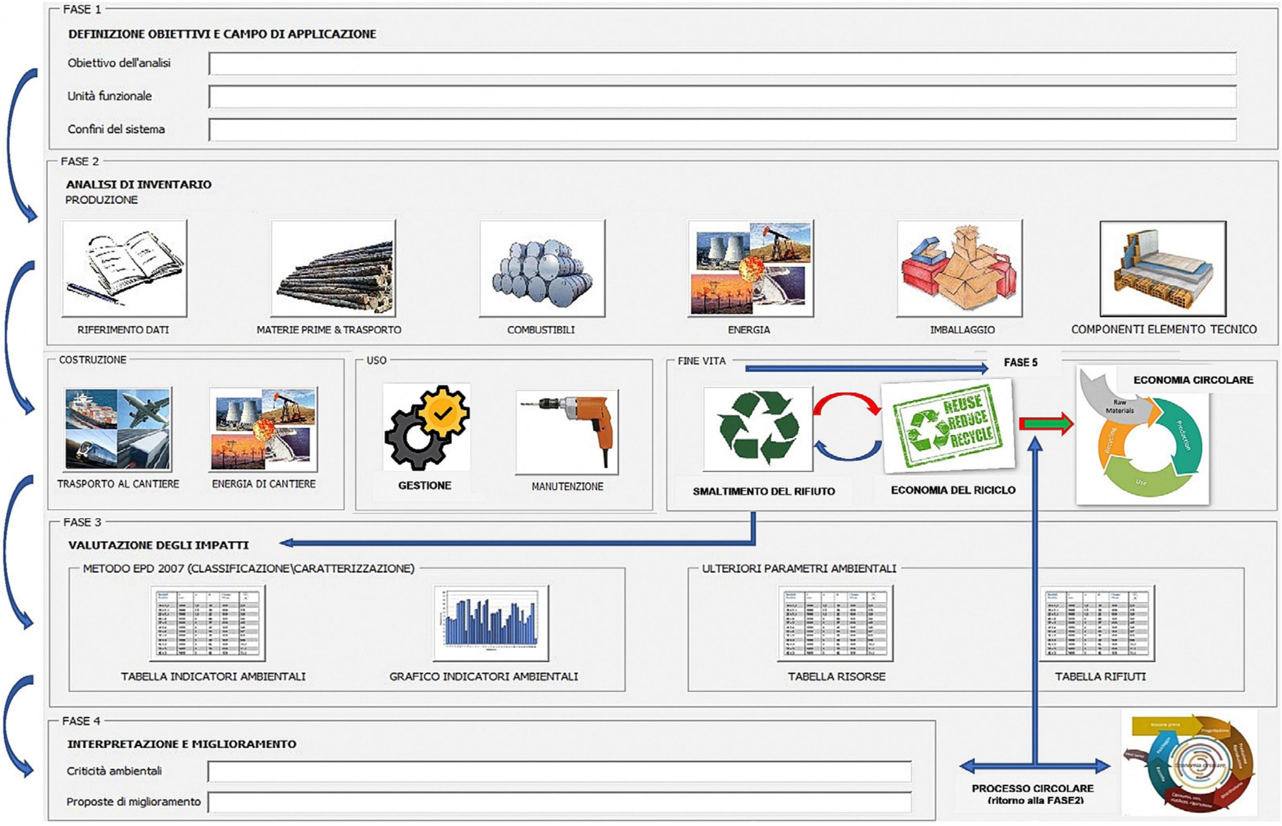


Figure 2 | Logical and operational phases of the analysis for the assessment of sustainable and circular durability (Marino & Marrone, 2020).

of the activities of the *Construction Technology Laboratory* (*La.Te.C.*) of the University of Basilicata (Local Research, 2004, 2006; Marino et al., 2006; Lembo & Marino, 2007).

It allows to produce an industrial wood of superior quality to Slavonian *Quercus robur*, at a highly competitive price, with a yellow-pink colour of great effect, very appealing (Fig. 3), which can be used for the construction of glulam pillars and beams, with performance three times higher than that of normal resinous glulam (for example, in bending it can work at 41.9 N/mm^2) (Fig. 4 and Table 1) (Lembo & Marino, 2007, 2008, 2015).

The hypothesis is to create a real *Cerro Lucano supply chain,* which could be an important factor of environmental protection, social equity and economic development (Local Research, 2003).

Figure 3 | Photo of a laminated conditioned *Quercus cerris* glulam specimen.

In fact, a research, always coordinated by the same first two authors, has shown that the increase in employment deriving from the enhancement of this resource, following the implementation of plans for improving and cultivating the woods; government of the territory; activation of sawmills, thermo-hygrometric conditioning systems, factories for the construction of structural elements in laminated conditioned wood and X-LAM; factories for the production of fixtures, parquet, derulated, veneered,

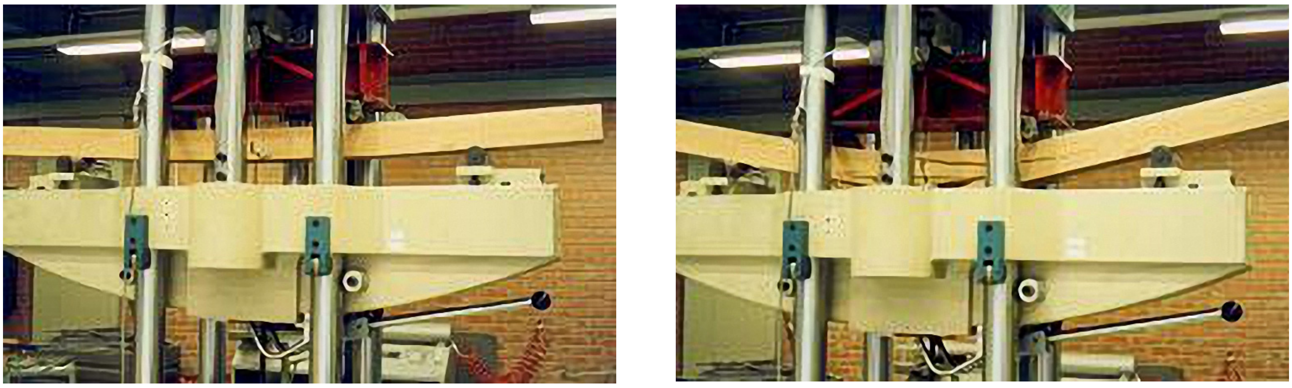


Figure 4 | Sequence of the simple flexion breakout test carried out on a laminated conditioned *Quercus cerris* beam.

Table 1 | Characteristic values of strength and elastic modulus of conditioned *Quercus cerris* (Turkey oak) wood (Laboratory tests conducted by the first two authors, according to relevant standards) (Local Research, 2002).

Class of resistance			*GL 24h*	*GL 28h*	*GL 32h*	*GL 36h*	*Quercus cerris*
Flection's characteristic resistance	$f_{m,g,k}$	N/mm²	24	28	32	36	102.2
Parallel traction's characteristic resistance	$f_{t,0,g,k}$	N/mm²	16.5	19.5	22.5	26	94.17
Perpendicular traction's characteristic resistance	$f_{t,90,g,k}$	N/mm²	0.40	0.45	0.50	0.60	2.09
Parallel compression's characteristic resistance	$f_{c,0,g,k}$	N/mm²	24	26.5	29	31	89.53
Perpendicular compression's characteristic resistance	$f_{c,90,g,k}$	N/mm²	2.7	3.0	3.3	3.6	9.94
Cutting's characteristic resistance	$f_{v,g,k}$	N/mm²	2.7	3.2	3.8	4.3	9.64
Mean parallel elastic modulus	$E_{0,g,mean}$	N/mm²	11600	12600	13700	14700	23413
Parallel elastic modulus 5th percentile	$E_{0,g,05}$	N/mm²	9400	10200	11100	11900	18953
Mean perpendicular elastic modulus	$E_{90,g,mean}$	N/mm²	390	420	460	490	780
Modulus of sliding	$G_{g,mean}$	N/mm²	720	780	850	910	1460
Main density	$r_{g,k}$	kg/m³	380	410	430	450	815,77

plywood, elements and objects of furniture; it would lead to an increase in employment estimated at 17,000 new jobs (Local Research, 2003). These results are comparable to those of other similar researches (Mitchell & Morgan, 2015; IISD, 2018; IISD-SITRA, 2020; SITRA 2021). It is not unnecessary to underline that the entire population of Basilicata was 562,869 inhabitants in 2019, down from 611,029 in 1990, and that employed persons are only 34.1% of the population (17th place out of 20 Italian regions by Activity Rate, 8th place of 20 for Unemployment Rate).

This new material could be used in the field of *conservation and refurbishment of building heritage*, allowing to use the same sections (and the same wood species) of the ancient building elements, while providing structural capacities six times higher (Lembo et al., 2007, 2018, 2019; Lembo & Marino, 2008, 2016; Marino & Lembo, 2017; Marino et al., 2019b, 2021).

This new material can obviously express all its possibilities also for the conception of *new ways of designing new buildings*, in particular if of considerable height, given the particularly advantageous ratio between density and structural performance (Local Research, 2008, 2015, 2016; Lembo & Marino, 2015; Lembo et al., 2016; Marino et al., 2019a).

Particularly interesting is the application to structures with base insulation and dissipative bracing techniques, due to the extreme efficiency and ductility of the resulting solutions (Local Research, 2016).

Because of the above has been said, what is presented here is a research based on a material not

Figure 5 | Aerial view of the town of Rionero at the foot of Monte Vulture; the arrow indicates the location of the school.

yet available from a commercial point of view; it is not the report of a professional assignment, but a study carried out at the *La.Te.C.*, aimed at investigating the advantages and possible criticalities of the use of this new material. The characteristics of the present nZEB project, based on the bioclimatic criteria of passive solar systems with direct gain; set on large structural meshes with point-like constraints that fulfil the canons of *Design for Adaptability*; and of the constructive system, with a positive energy balance (Lembo et al., 2015, 2016; Marino et al., 2019b; Local Research 2015), are such as to allow their complete *disassembling, reuse and recycling*, both for the structural parts and for the completions and finishes. It is thus possible to fully achieve the objectives of *sustainability* and *circularity in construction*, through a building configuration aimed at soliciting intelligent, aware and pleasant participation by users and all citizens.

Figure 6 | Orthophoto of the intervention area and overall view of the M. Preziuso primary School.

2. The site, the existing "M. Preziuso" primary school and the building program

The city of Rionero (just over 13,000 inhabitants), in the province of Potenza, rises at the foot of the extinct volcano of Vulture (Fig. 5) with the lakes of Monticchio and large deciduous woods; it is a land of famous Aglianico wines and mineral waters, both of which are sent all over the world. Between 1949 and 1963 an elementary school was built, with a reinforced concrete structure, later named M. Preziuso, with distributive and formal characteristics typical of fascist rationalism (Fig. 6).

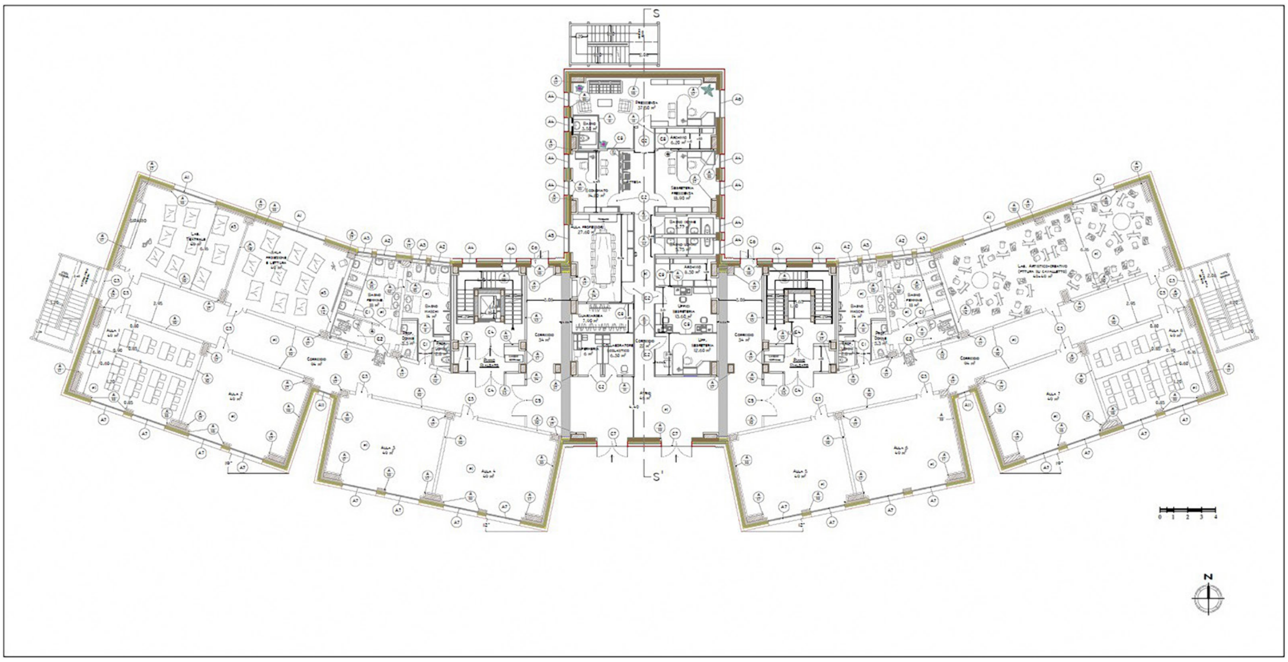


Figure 7 | Raised floor plan.

Damaged by 1980 earthquake, the school had received a series of structural consolidation intervention, but in April 2016 a stone infill wall collapsed. A subsequent seismic vulnerability analysis of the building declared it in need of interventions of such magnitude that it cannot be recovered. The Municipal Administration is preparing to decide on its demolition and reconstruction. The building complex should now go from 12 to 24 classrooms, to bring together activities that now take place in different buildings, on an area that, incorporating an adjacent abandoned warehouse, would reach 16,000 m^2.

The site is located at an altitude between 618 and 627 m asl, with an average slope of 5-6%, lat. N 40°92', long. E 15°66', and a good exposure to the sun toward South. The soil is made of 'lahar', the flood of muds that flows along the slope of a volcano, slightly thickened for the first 10 m, and then more coherent: it needs of foundation on piles. It is seismic zone I, with high dangerousness (acceleration with probability of exceeding of 10% in 50 years: $a_g \leq 0.25$ g).

The climate is that of the Mediterranean mountain climate: cold and snowy in winter time, tepid in summer time. Coldest month is January, with average temperature of +4.4 °C, hottest August, with average temperatures of 21.8 °C. The proximity of the two lakes of Monticchio and the forest make the climate humid; rainfall is between 68 mm in November and 25 mm in July. Important is the relative average annual moistness, equal to about 80% for the most of months (but July and August, when she seizes between 50% and 65%).

Therefore, it is necessary to forecast systems of mechanical controlled ventilation equipped not only with heat recovery device, but also with dehumidifier. Winds in summer months come from 240° (West-South-West, *Libeccio*) and in the winter from 30° (North-East, *Grecale*), with speed between 5 and 6 m/s. Solar radiation is high, thank to air clearness. It is climatic zone E, with 2.144 degrees-day (heating from October 15 to April 15, 14 hours daily).

3. Design according to passive solar criteria

One of fundamental requirements of a *sustainable building* is that which enhances natural resources and exploits the free energy inputs of the sun, wind, earth (to possibly cool down) (and water, but not in an already humid climate like that of the case under consideration).

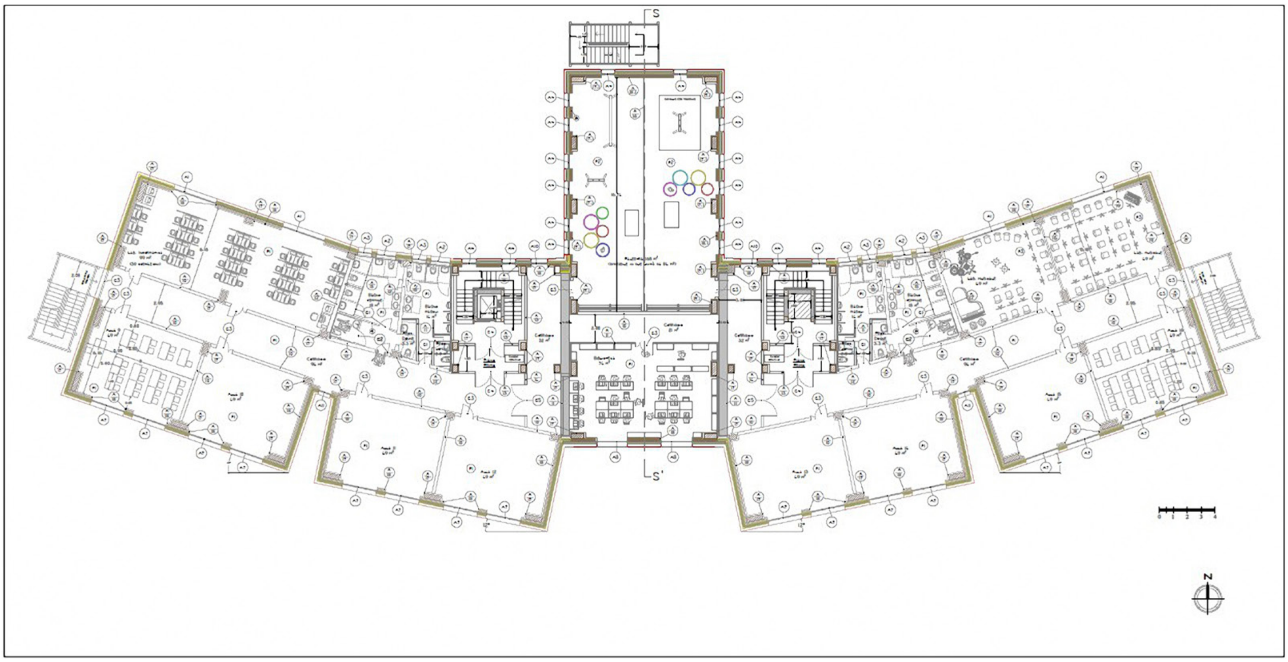


Figure 8 | First floor plan.

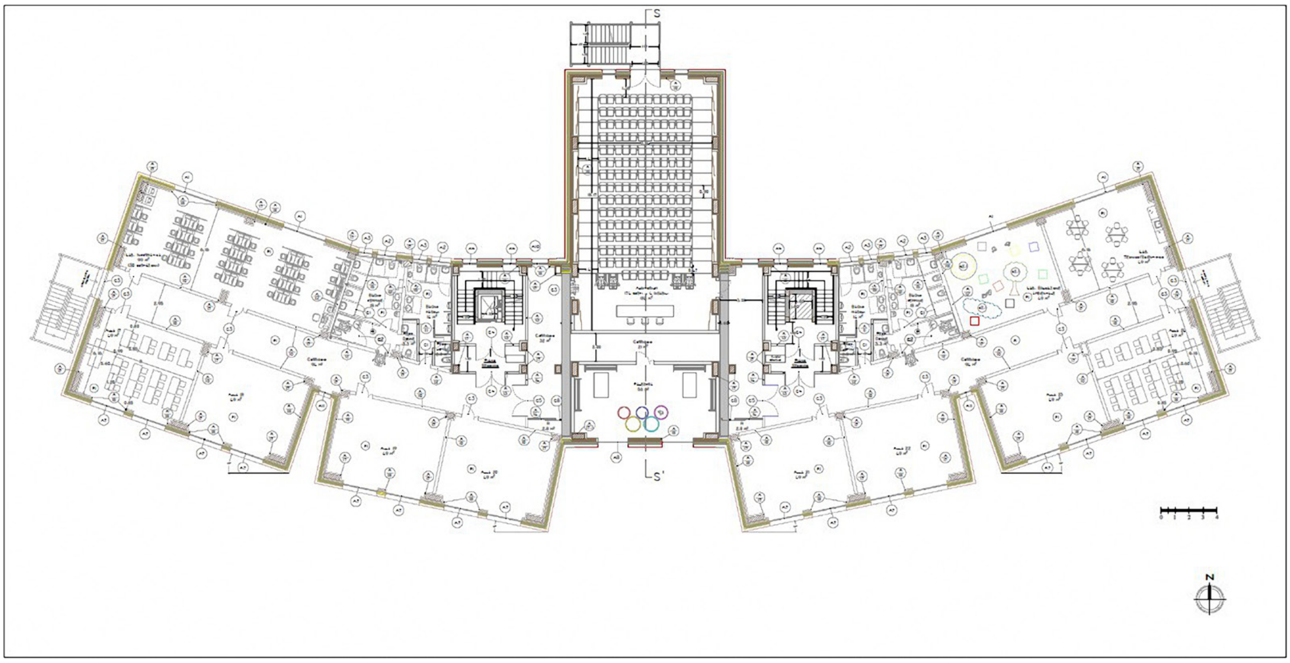
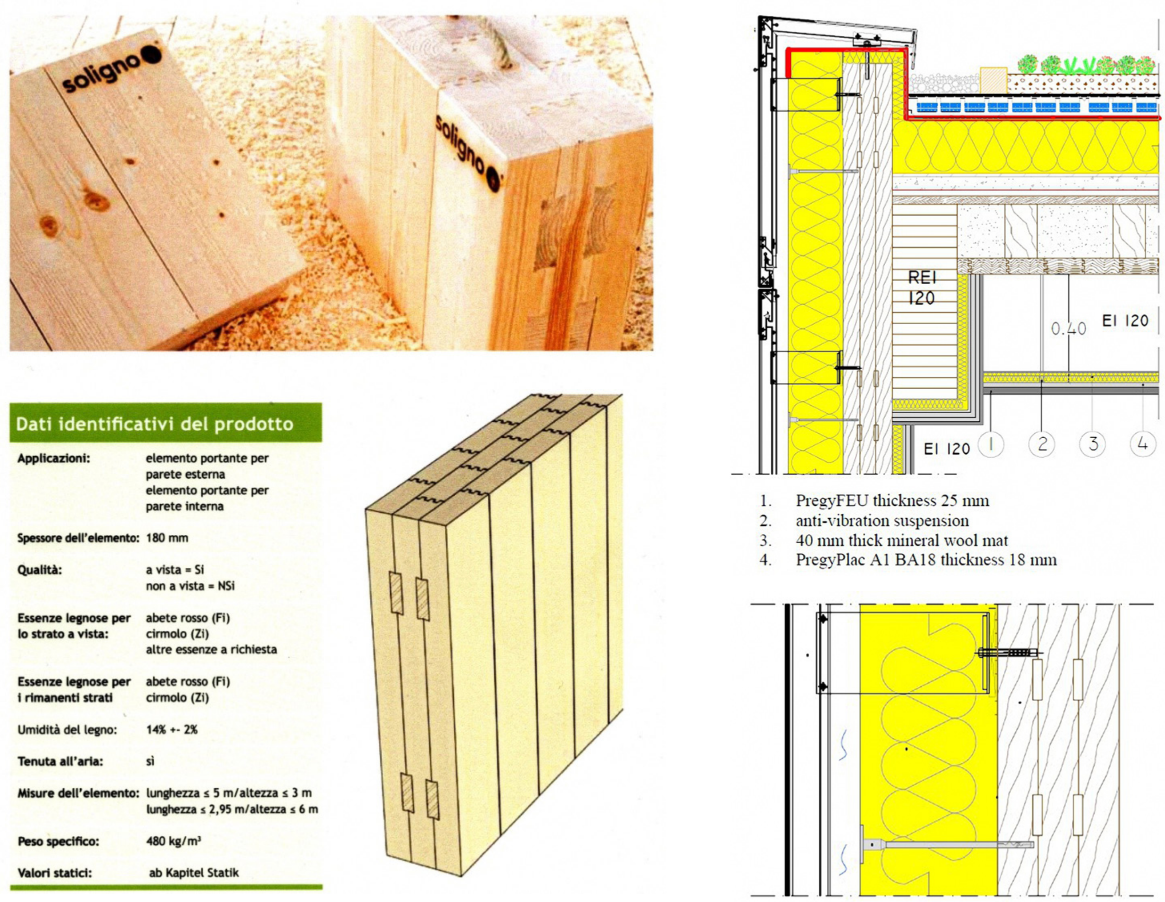


Figure 9 | Second floor plan.

To use the words of Edward Mazria: "*this implies a particular relationship with natural processes, which offers the possibility of an inexhaustible supply of vital energy*" (Mazria, 1980). For this reason, the school project was set up by providing a compact building with three floors, with normal classrooms, in which the students are most of the time, on the West-East alignment, in order to open to the South windows larger than required by standard; while the offices, special classrooms, gyms, auditorium and toilets are turned to the North (Figg. 7-9).



Dati identificativi del prodotto	
Applicazioni:	elemento portante per parete esterna elemento portante per parete interna
Spessore dell'elemento:	180 mm
Qualità:	a vista = Si non a vista = NSi
Essenze legnose per lo strato a vista:	abete rosso (Fi) cirmolo (Zi) altre essenze a richiesta
Essenze legnose per i rimanenti strati	abete rosso (Fi) cirmolo (Zi)
Umidità del legno:	14% +- 2%
Tenuta all'aria:	sì
Misure dell'elemento:	lunghezza ≤ 5 m/altezza ≤ 3 m lunghezza ≤ 2,95 m/altezza ≤ 6 m
Peso specifico:	480 kg/m³
Valori statici:	ab Kapitel Statik

1. PregyFEU thickness 25 mm
2. anti-vibration suspension
3. 40 mm thick mineral wool mat
4. PregyPlac A1 BA18 thickness 18 mm

Figure 10 | Perimeter walls in *Soligno®180* panels: data sheet, construction detail of the roof, current vertical section on *Alucobond* ventilated rainscreen.

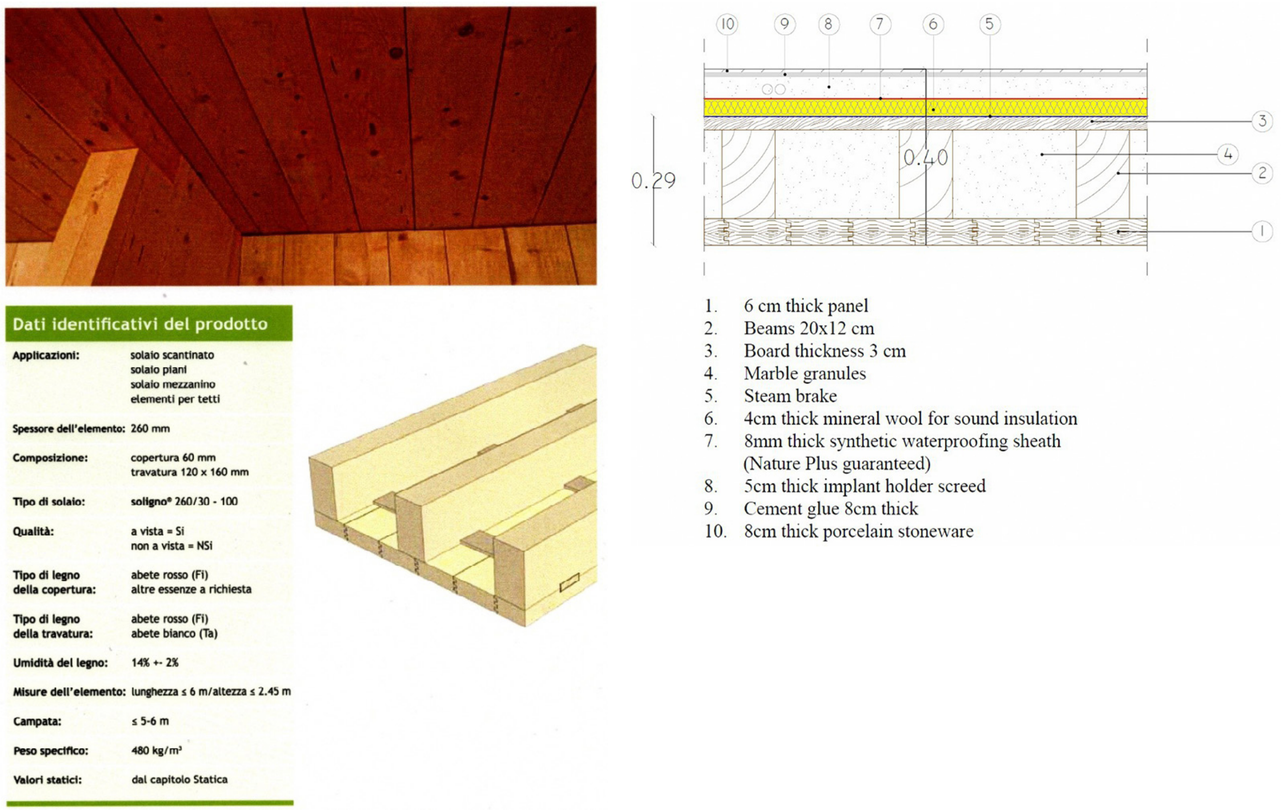
In a passive solar building "direct gain", in addition to the large windows facing South, it is necessary to have a storage system and an effective insulation from the outside, of great thickness. In this project the inertia is provided by the perimeter walls in *Soligno®180* panels, 180 mm thick and made up of three series of spruce and pine boards dry-stitched without glue (Fig. 10); the *Soligno®260* floors, also of similar construction, 260 mm high and with spans up to 6.00 m (Fig. 11); and from the same structure, in *Quercus cerris* conditioned glulam, with pillars of variable size, according to the calculation, from 240 × 280 mm to 360 × 520 mm and up to 360 × 1400 mm; and with beams also in the same material, with dimensions ranging from 240 × 280 mm to 240 × 920 and 360 × 720 mm (Figg. 10 and 11).

Insulation is provided: on the ground, by 1 cm of XPS (Fig. 14); on the external walls, by 4 + 20 cm of mineral wall with $\lambda = 0{,}037$ W/mK in the ventilated rainscreen (Fig. 10); on the roof, by a 'green roof' and 20 cm of mineral wool (Fig. 10). The windows are provided in wood-PU-aluminium, with triple glazing and integrated slatted shading, $U_w = 0{,}60$ W/m^{2}K. The result is that of an nZEB building (Fig. 15).

Obviously, all the wooden construction elements are expected to be protected from fire for 120 minutes, by means of coatings and false ceilings in mineral wool and plasterboard *Firestop®*.

4. Post-tension and passive dissipation system for the central part of the building

For the central part of the building, in which there are spans of 10.10 m, the use of the post-tensioning system *Pres-Lam*, specific for laminated wood construction systems, was forecast (Figg. 12, 16 and 18). It has until now used only for



Dati identificativi del prodotto

Applicazioni:	solaio scantinato solaio piani solaio mezzanino elementi per tetti
Spessore dell'elemento:	260 mm
Composizione:	copertura 60 mm travatura 120 x 160 mm
Tipo di solaio:	soligno® 260/30 - 100
Qualità:	a vista = Si non a vista = NSi
Tipo di legno della copertura:	abete rosso (Fi) altre essenze a richiesta
Tipo di legno della travatura:	abete rosso (Fi) abete bianco (Ta)
Umidità del legno:	14% +- 2%
Misure dell'elemento:	lunghezza ≤ 6 m/altezza ≤ 2.45 m
Campata:	≤ 5-6 m
Peso specifico:	480 kg/m³
Valori statici:	dal capitolo Statica

1. 6 cm thick panel
2. Beams 20x12 cm
3. Board thickness 3 cm
4. Marble granules
5. Steam brake
6. 4cm thick mineral wool for sound insulation
7. 8mm thick synthetic waterproofing sheath (Nature Plus guaranteed)
8. 5cm thick implant holder screed
9. Cement glue 8cm thick
10. 8cm thick porcelain stoneware

Figure 11 | *Soligno®260* floors: data sheet, construction detail of a suspended floor.

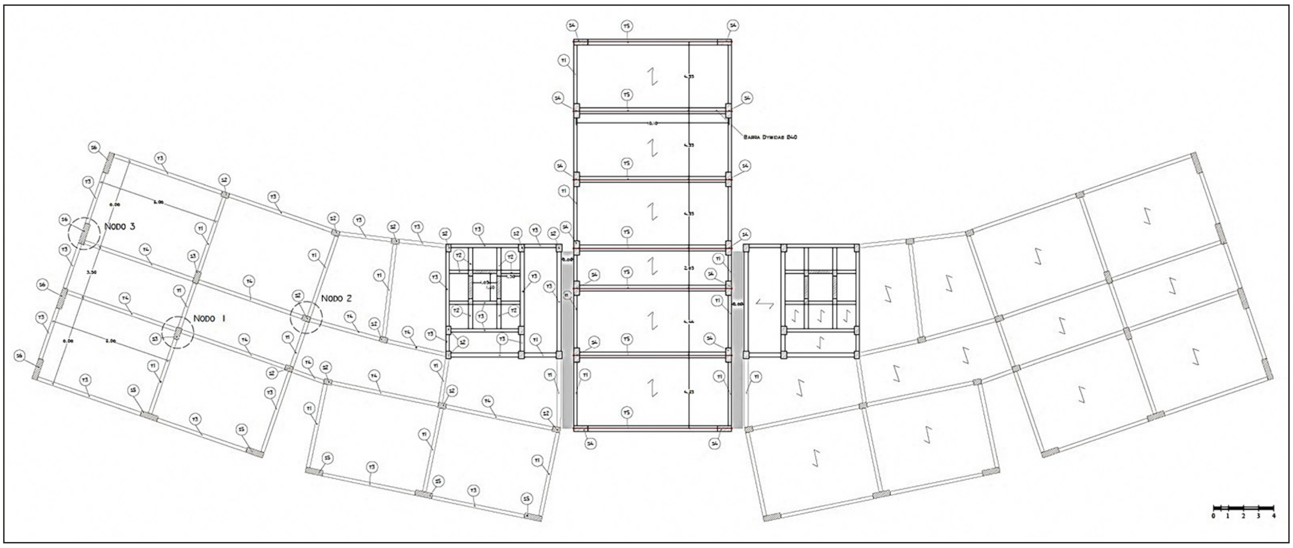


Figure 12 | Structural plan of the first floor.

softwood glulam, and was originally developed since 2004 by the University of Canterbury in New Zealand. The application to the new engineered hardwood glulam is being studied in the *Materials and Structures Test Laboratory – SisLab*, School of Engineering of the University of Basilicata – Potenza. It has one of the greatest *vibrating tables with contrast wall* in Italy, which allows the carrying out of seismic tests on buildings in real size (Fig. 17). In the case at hand, the use of steel bars DYWIDAG 40WR for levels 1 and 2, and 36WR for the roof was envisaged. It is coupled

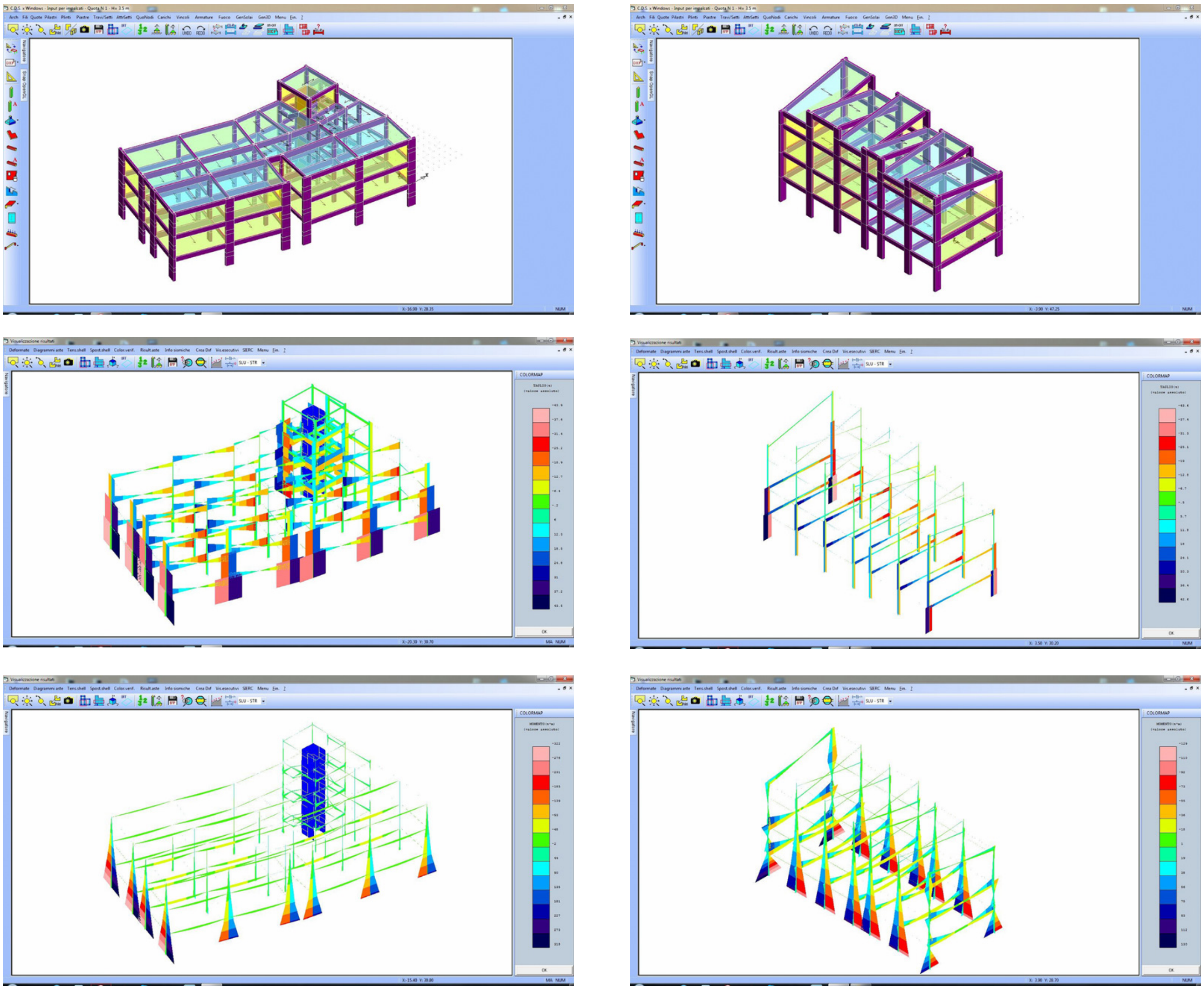


Figure 13 | Modelling of the structure and envelope of combination of bending moment and shear stresses, both of the West wing body (left) and of the central part of the building (right).

to a system of passive dissipation of seismic energy, made through yieldable steel angles or "plug and play" axial devices (Fig. 16, already seen).

5. Architectural concept

Learning is a game and everyone can achieve seemingly impossible goals. This is the architectural *concept* of the building, which is inspired by the famous *magic cube* invented by the Hungarian sculptor and architect Ernö Rubik in 1974. It is a game of logic that, initially spread only among Hungarian mathematicians interested in the statistical and theoretical problems it posed (allows 43 million billion configurations), it was actually designed for educational purposes.

It is *polysense* at the highest degree; it has been defined "*creative game par excellence*" and is the most popular toy in history, with more than three hundred million pieces. It can be considered the emblem of sustainability in games: it is cheap, has no batteries, it is non powered by other energy than intelligence. It is therefore a symbol of creativity, perseverance, equality. Identify the school as a play object (Fig. 19).

The play of colours of the "*cubes*" of the facades becomes more accentuated on the roof of the central part, where the volumes "*deconstruct*", losing the elementary geometry of the lateral parts and introducing an unstable geometry, in which chaos is the ordering element, according to what the most up-to-date mathematics and physics suggest. To quote

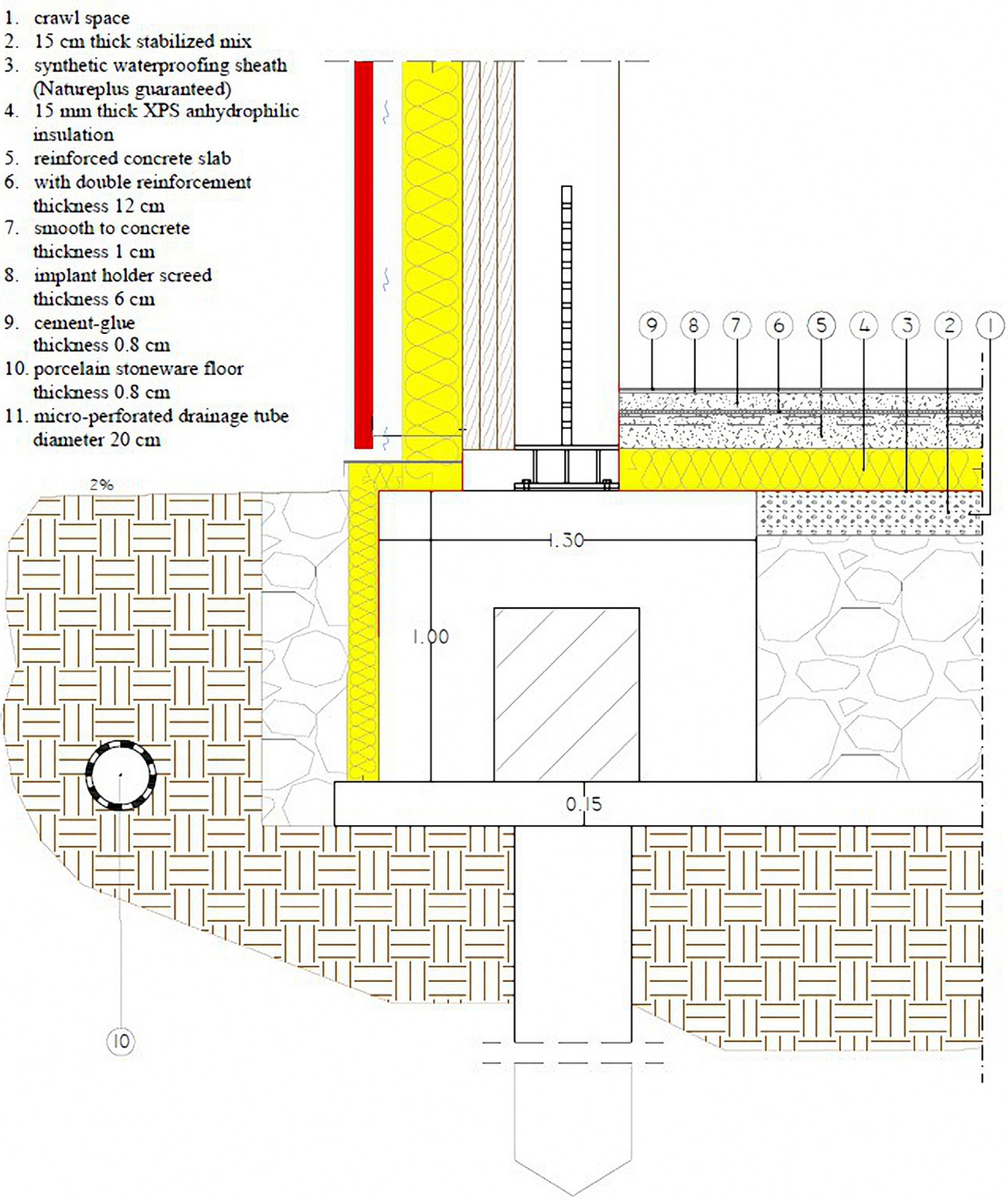


Figure 14 | Detail of the ground connection.

Giovanni Villani 2008, p. 17: "The organization produces order that preserves the organization that produced it. In practice, the order/organization relationship is of a circular type…However, disorder is not eliminated from the organization and remains in the system and, therefore, alongside a "principle of organization", there is a "principle of disorganization" which reminds us that no organized thing, no organized being can escape degradation, to disorganization, to dispersion, no living can escape death; that every creation, every generation, every development and every information must be paid in entropy and that no system, no being can escape death or regenerate spontaneously."

It is not useless to recall, among the most active de-constructivists on the international level, Coop-Himmelb(l)au, Frank O. Gehry, Zaha Hadid (now Patrik Schumacher), Daniel Libeskind. Hence the choice, for the external cladding of the ventilated rain screen and the covering of the central part, of *Alucobond®A2* sheets, which make it possible to have pure, homogeneous and brilliant colours, completely equal to those of the reference *cube* (Fig. 20).

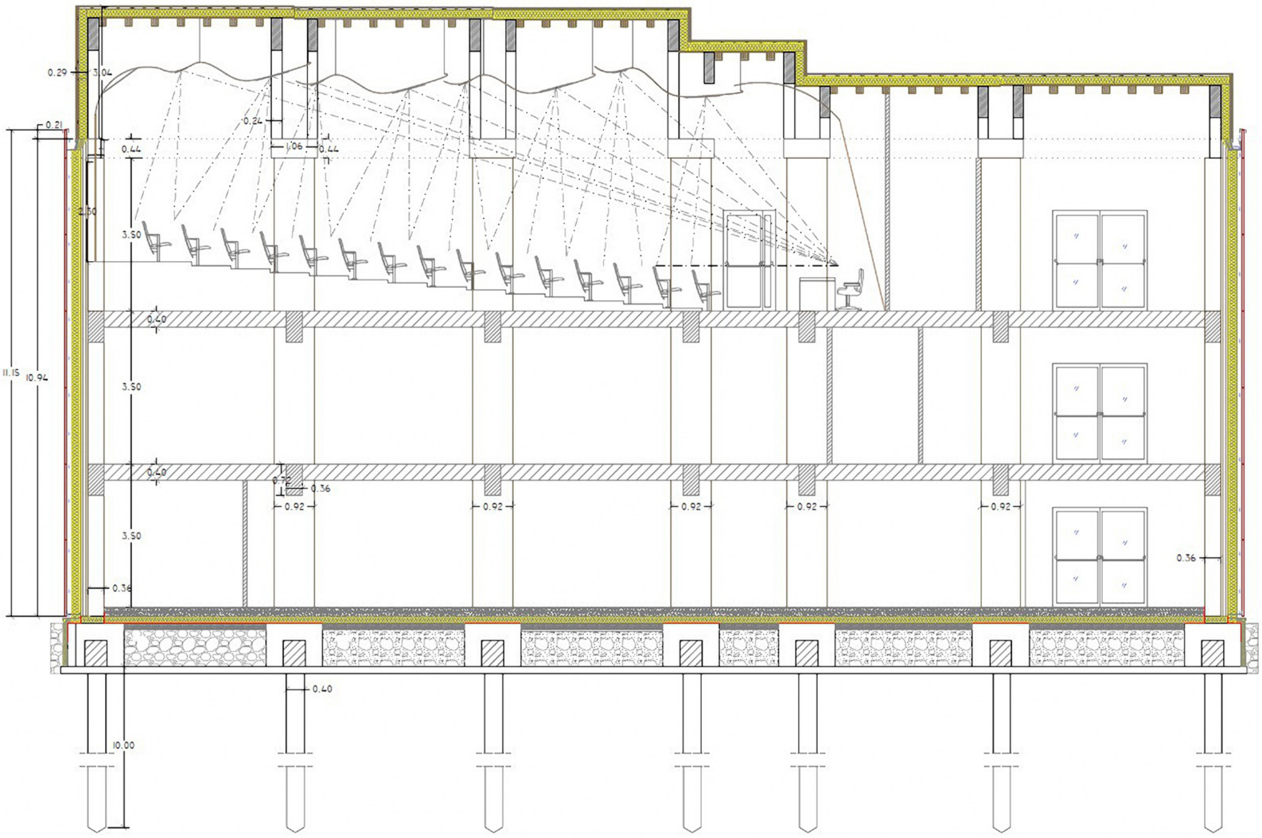


Figure 15 | Cross section on the central part.

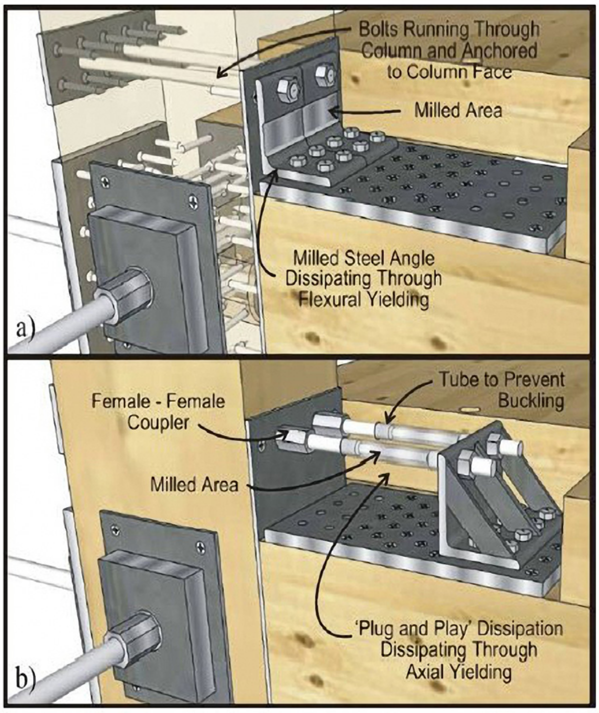


Figure 16 | Two dissipation methods that can be applied to the PRES-LAM Post-Compression system: a) the angle bars in yieldable steel; b) the axial device called "plug and play".

Figure 17 | *SisLab* Unibas: real-scale wooden building under seismic test.

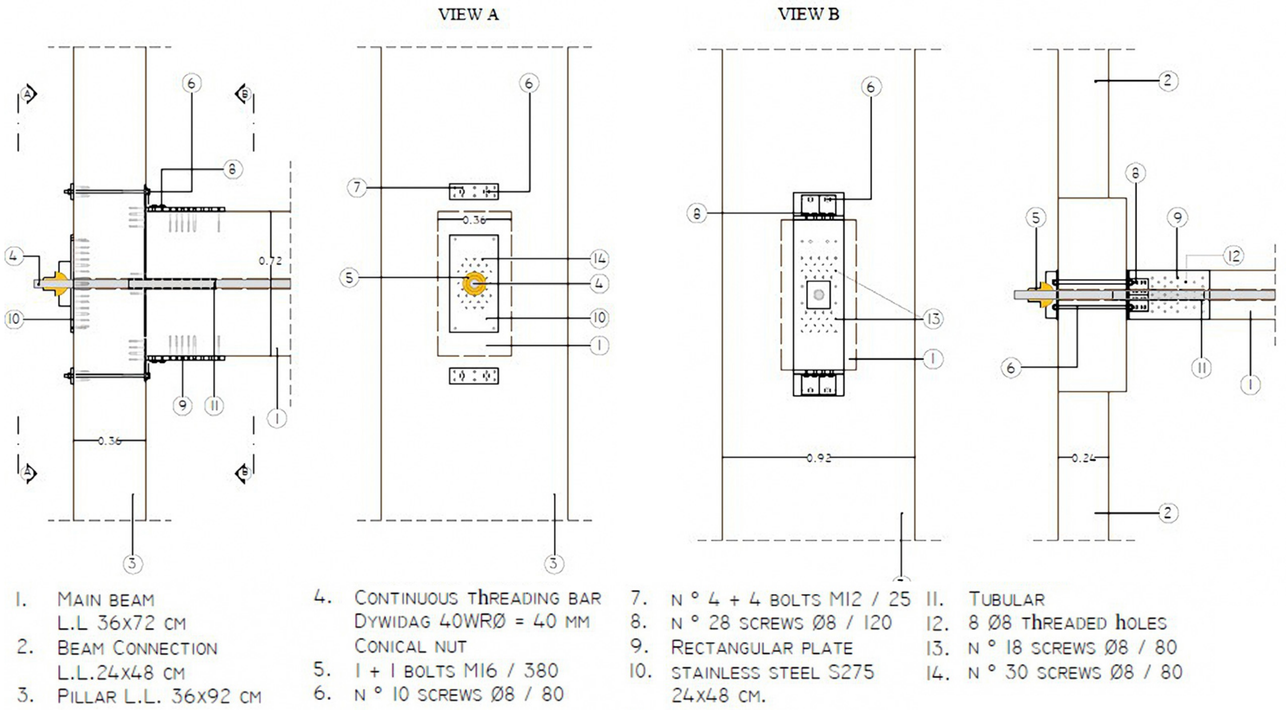


Figure 18 | Detail of the *Pres-Lam* System node.

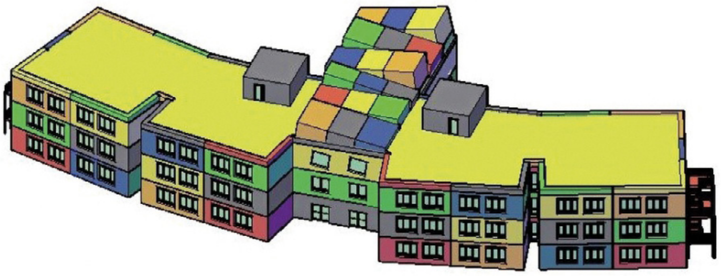


Figure 19 | Axonometric South view of the school.

Figure 20 | View of the main elevation facing South.

6. The plant solutions

Three double-flow Controlled Mechanical Ventilation systems (one per floor) with heat recovery units (*Zehnder ComfoAir XL 6000*) and dehumidification devices (*Zehnder ComfoDew 500*) have been planned for the building, with the distribution channels arranged in the large false ceiling set below the floors.

CO_2 level detectors are applied to the outgoing pipes from the classrooms and other spaces, which control the butterfly valves arranged on the incoming pipes, adjusting the flow rate in relation to the level of attendance. Presence detectors provide for the exclusion of unused rooms.

Following the example of the Dutch schools of Aldo Van Eyck and Hermann Herzberger, windows of the classrooms have the sill 70 cm high from the floor, so that from the classroom there is more contact with the outside than usual, and that windows can be equipped, in the lower part, with ‘visor’ openings towards the outside; in the upper part, the windows have similar openings that open ‘vasistas’ inwards. In this way, in spring, summer or autumn, if the ventilation system is switched off, you can naturally ventilate the spaces in an optimal way, without opening the doors to the corridors. About this, applying in the most scrupulous way the regulations in force relating to the design of acoustic comfort, great attention has been paid to acoustic insulation against airborne and impact noise in all spaces, in particular those intended for toilets (it is perhaps worth remembering that the water discharge of a toilet cassette produces a noise of an intensity equal to 80 dB). In the same way, you have provided materials for walls, ceilings and floors that can determine low reverberation times, even lower than those required by current standards, and this not only for the auditorium, gyms and classrooms, but also for offices and corridors, in order to guarantee the highest acoustic comfort.

As for heating system, two *Aermec ANL202HP-HA* heat pumps have been provided, with a useful power of 61.86 kW each and a fan coil system, which allows minimum start-up times due to its low thermal inertia, low temperature of the heating fluid, greater air cleaning, thanks to the dust and impurity filters the fan coils are equipped with. Furthermore, they guarantee the mixing of the air, avoiding its stratification, and are powered by renewable energy sources.

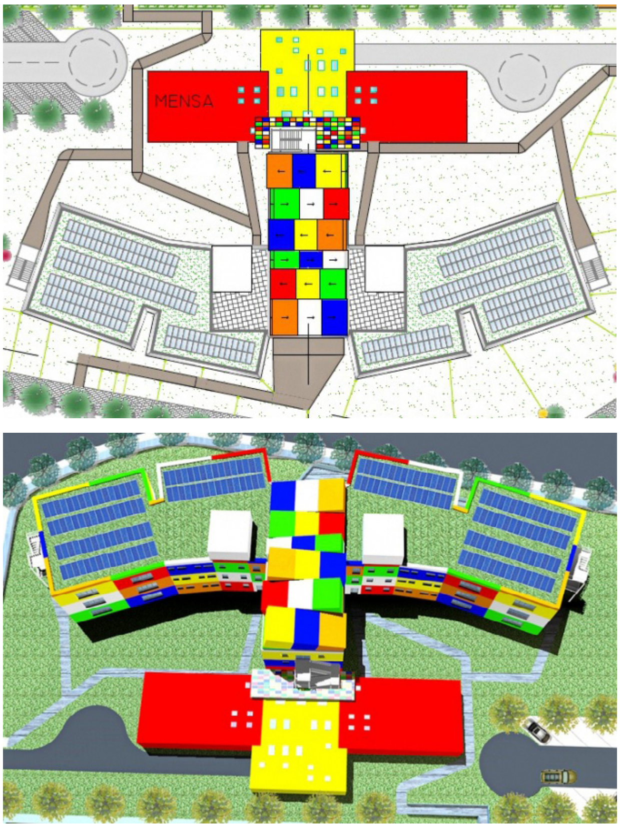
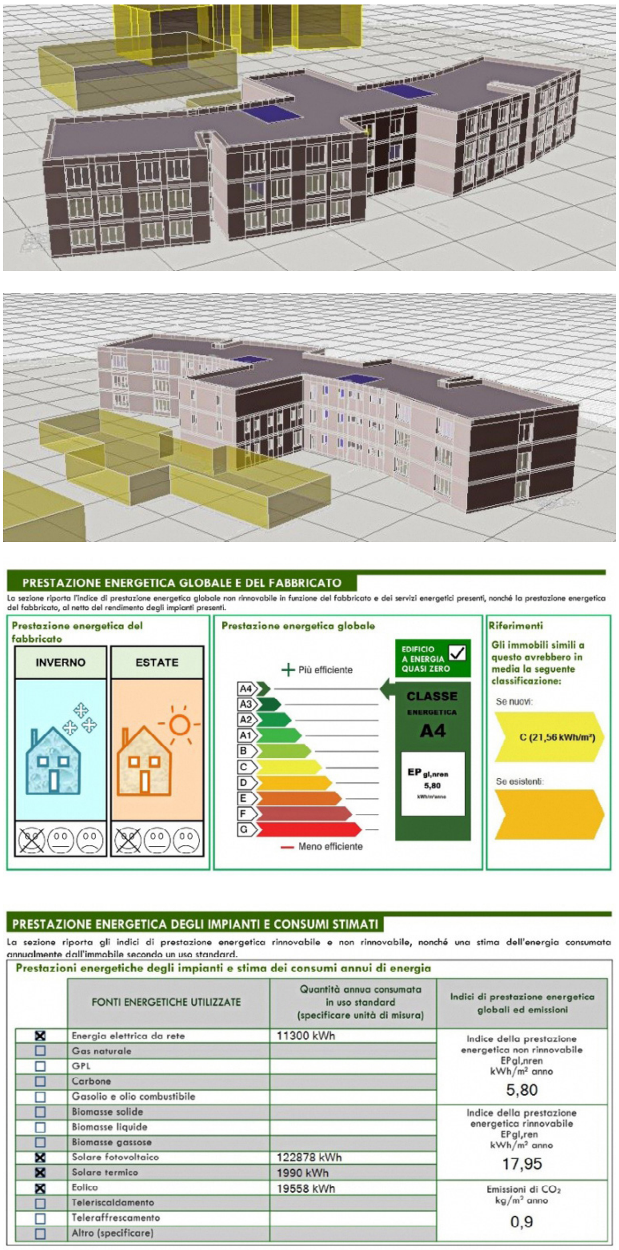


Figure 21 | Plan and 3d photorealist view with location of the photovoltaic and solar thermal panels.

Figure 22 | Overall 3d photorealistic view.

It has been foreseen that the energy needed by the school is provided by 350 *Sony* photovoltaic panels, for 483 m^2 of surface, capable of producing 122.9 kWp, arranged on the roof of the two wings of the building, together with the solar panels for the production of domestic hot water (Fig. 21). In addition, two *Aeolos* vertical axis wind turbines of 10 kWp each have been planned (Fig. 22), arranged in an area free from obstructions on the western edge of the area.

They are not very noisy (less than 45 dB), and are activated with low wind speeds, starting from 2.5 m/s. Each of them can produce around 23,500 kWh per year.



PRESTAZIONE ENERGETICA GLOBALE E DEL FABBRICATO

La sezione riporta l'indice di prestazione energetica globale non rinnovabile in funzione del fabbricato e dei servizi energetici presenti, nonché la prestazione energetica del fabbricato, al netto del rendimento degli impianti presenti.

Prestazione energetica del fabbricato

INVERNO

ESTATE

Prestazione energetica globale

EDIFICIO A ENERGIA QUASI ZERO ☑

CLASSE ENERGETICA A4

EP gl,nren 5,80 kWh/m²anno

Riferimenti

Gli immobili simili a questo avrebbero in media la seguente classificazione:

Se nuovi: C (21,56 kWh/m²)

Se esistenti:

PRESTAZIONE ENERGETICA DEGLI IMPIANTI E CONSUMI STIMATI

La sezione riporta gli indici di prestazione energetica rinnovabile e non rinnovabile, nonché una stima dell'energia consumata annualmente dall'immobile secondo un uso standard.

Prestazioni energetiche degli impianti e stima dei consumi annui di energia

	FONTI ENERGETICHE UTILIZZATE	Quantità annua consumata in uso standard (specificare unità di misura)	Indici di prestazione energetica globali ed emissioni
☒	Energia elettrica da rete	11300 kWh	Indice della prestazione energetica non rinnovabile EPgl,nren kWh/m² anno 5,80
☐	Gas naturale		
☐	GPL		
☐	Carbone		
☐	Gasolio e olio combustibile		
☐	Biomasse solide		Indice della prestazione energetica rinnovabile EPgl,ren kWh/m² anno 17,95
☐	Biomasse liquide		
☐	Biomasse gassose		
☒	Solare fotovoltaico	122878 kWh	
☒	Solare termico	1990 kWh	
☒	Eolico	19558 kWh	Emissioni di CO_2 kg/m² anno 0,9
☐	Teleriscaldamento		
☐	Teleraffrescamento		
☐	Altro (specificare)		

Figure 23 | *Termolog* three-dimensional modeling and energy certification result.

The Energy Certification, carried out with software *Termolog*© by LogicalSoft, in *Open BIM* and according to UNI EN ISO 52016-1 and 52017-1 dynamic hourly calculation, relating to a gross heated volume of 15,197 m^3, with a useful surface of 3,700 m^2 and a dispersing surface of 2,046 m^2, showed a *non-renewable global energy performance index* $EP_{gl,\ nren} = 5.40$ kWh/m^2 per year, that places the building in the best performing category of Italian standard, A4 nZEB, with a CO_2 consumption of 0.9 kg/m^2 per year (Fig. 23).

7. Conclusions

The lively and playful aspect –of an intelligence game– which constitutes the message of the importance of mind in contemporary culture, covers a building whose substance has a profound meaning of possible redemption and relaunch for the economy of a Region, whose economy is still one of the least developed in Italy.

While, in the resources that Nature has given, it can find the means through which to plan a lasting and fully sustainable development.

Research has therefore shown how it is possible, through the engineered conditioning of the Lucan *Quercus cerris* wood, to create buildings whose environmental footprint is positive, durable, adaptable, resilient and resistant to earthquakes of the highest intensity, which can be dis-assembled and re-used; with spatial, formal and technological performances at the top of the range. Buildings with nZEB energy consumption, which can be powered by renewable resources. Furthermore, when evaluated with cradle-to-cradle LCA analyses, they prove to be able to fully meet the requirements of the Circular Economy.

Contributions

F. Lembo coordinated and provided the research objectives. F.P.R. Marino has developed the various aspects of research, the methodological and operational tools and verified the accuracy of research results. C. Di Lucchio carried out specific analyses in her Master's degree thesis. The authors' contribution in manuscript revision, editing and writing the text of the paper, was the same.

Acknowledgments

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