



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.

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.

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.

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

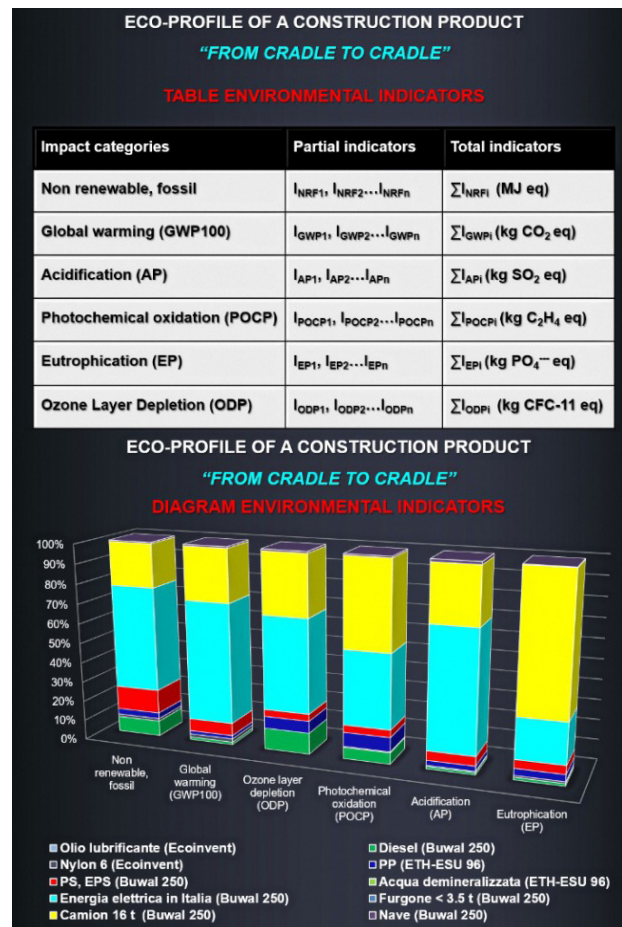


Figure 1 | Table and diagram of environmental indicator, referring to an example of eco-profile of a construction product in a Cradle-to-Cradle LCA analysis, performed with software EABM (P-product and TE-technical element), developed by the first two authors (Local Research, La.Te.C., Construction Technology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

in 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

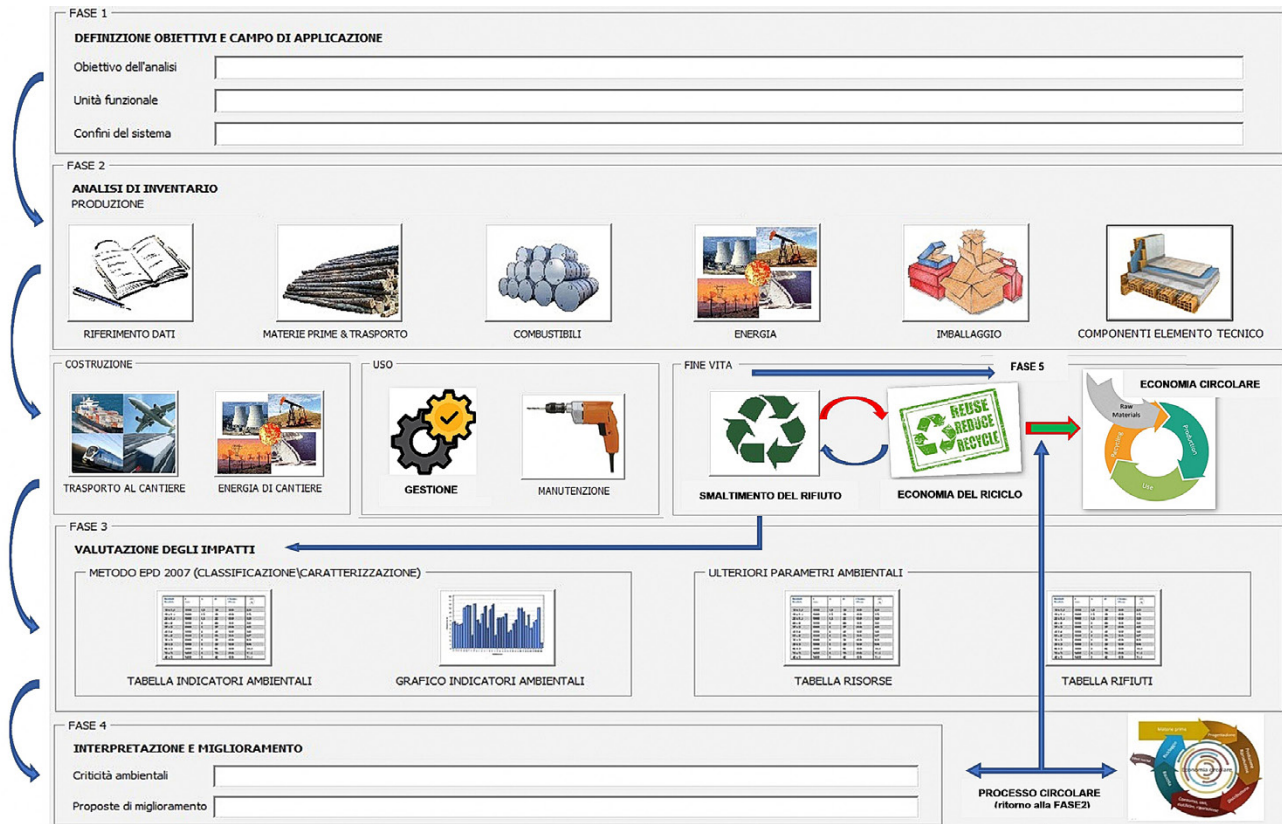


Figure 2 | Logical and operational phases of the analysis for the assessment of sustainable and circular durability (Marino & Marrone, 2020).

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/mm²) (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).

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



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

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,

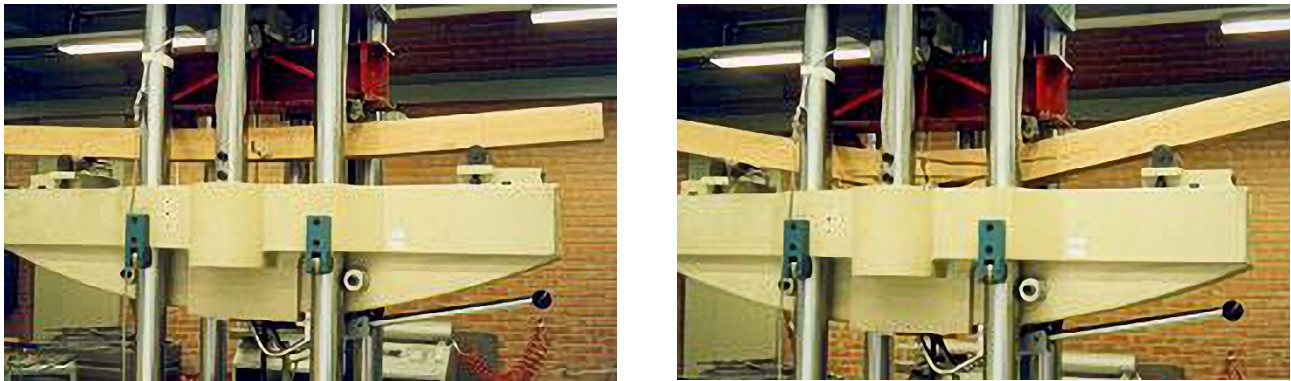


Figure 4 | Sequence of the simple flexion breakout test carried out on a laminated conditioned *Quercus cerris* beam.

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	<i>Quercus cerris</i>
Flexion's characteristic resistance	$f_{m,g,k}$	N/mm ²	24	28	32	36	102.2
Parallel traction's characteristic resistance	$f_{t,0,g,k}$	N/mm ²	16.5	19.5	22.5	26	94.17
Perpendicular traction's characteristic resistance	$f_{t,90,g,k}$	N/mm ²	0.40	0.45	0.50	0.60	2.09
Parallel compression's characteristic resistance	$f_{c,0,g,k}$	N/mm ²	24	26.5	29	31	89.53
Perpendicular compression's characteristic resistance	$f_{c,90,g,k}$	N/mm ²	2.7	3.0	3.3	3.6	9.94
Cutting's characteristic resistance	$f_{v,g,k}$	N/mm ²	2.7	3.2	3.8	4.3	9.64
Mean parallel elastic modulus	$E_{0,g,mean}$	N/mm ²	11600	12600	13700	14700	23413
Parallel elastic modulus 5th percentile	$E_{0,g,05}$	N/mm ²	9400	10200	11100	11900	18953
Mean perpendicular elastic modulus	$E_{90,g,mean}$	N/mm ²	390	420	460	490	780
Modulus of sliding	$G_{g,mean}$	N/mm ²	720	780	850	910	1460
Main density	$\rho_{g,k}$	kg/m ³	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.

2. The site, the existing “M. Prezioso” 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



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

elementary school was built, with a reinforced concrete structure, later named M. Prezioso, with distributive and formal characteristics typical of fascist rationalism (Fig. 6).

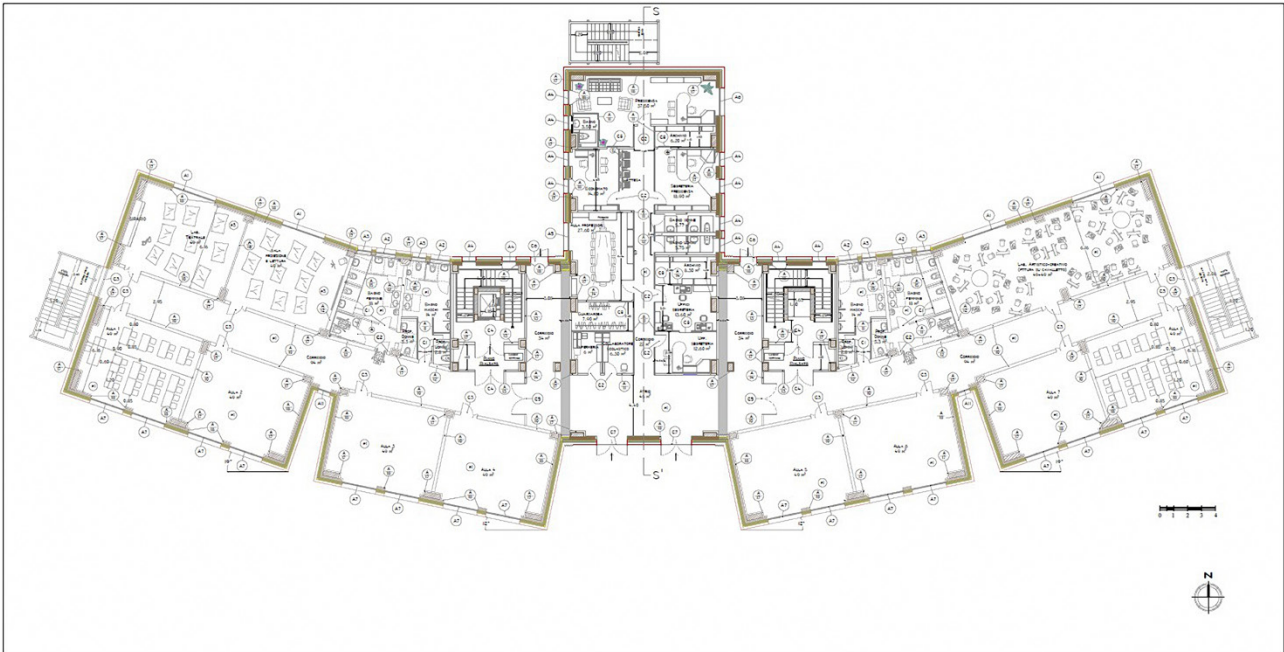


Figure 7 | Raised floor plan.

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 m².

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).

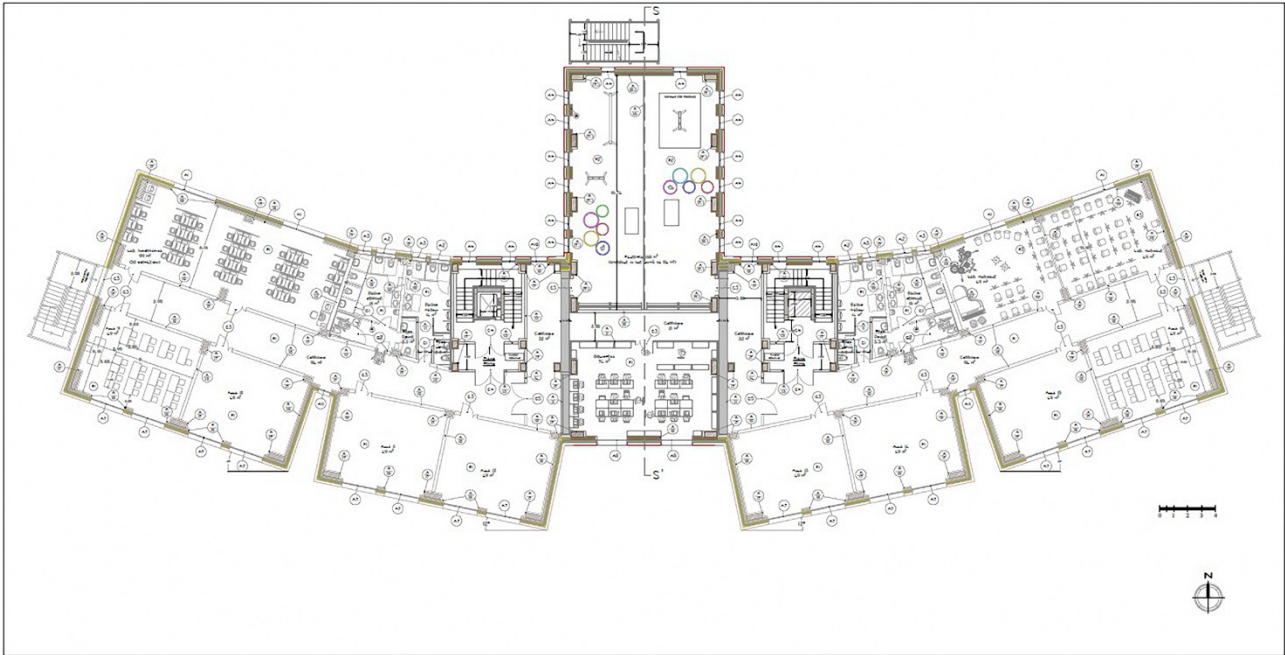


Figure 8 | First floor plan.

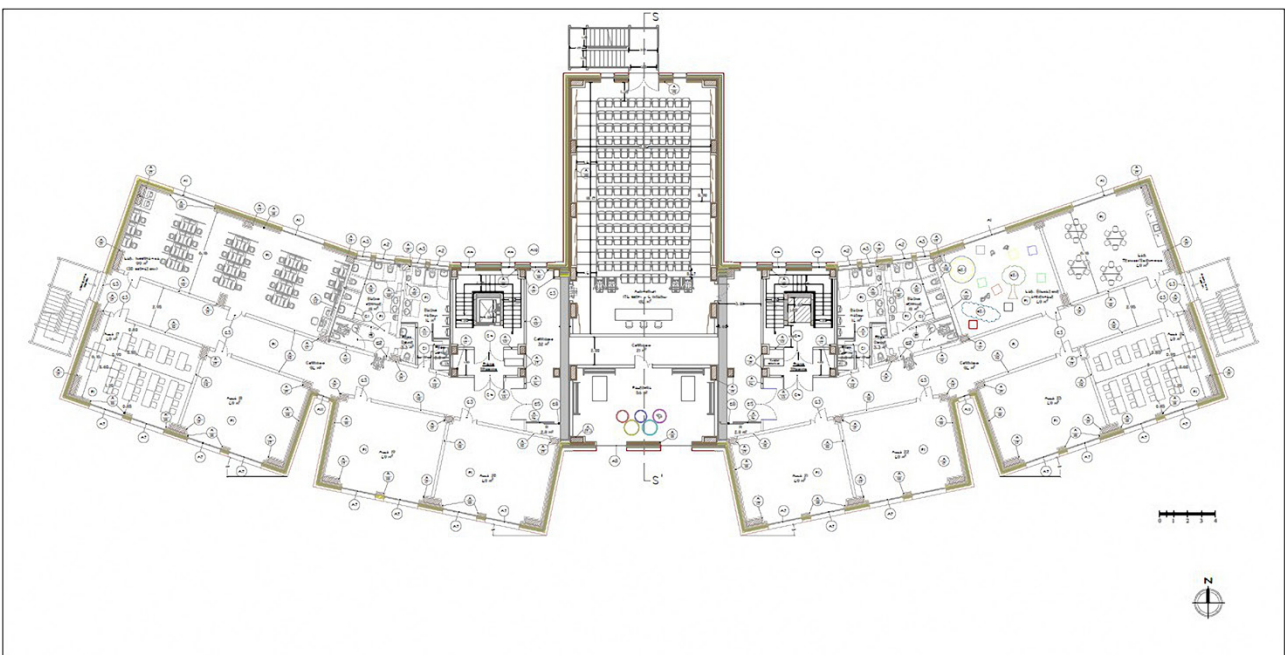


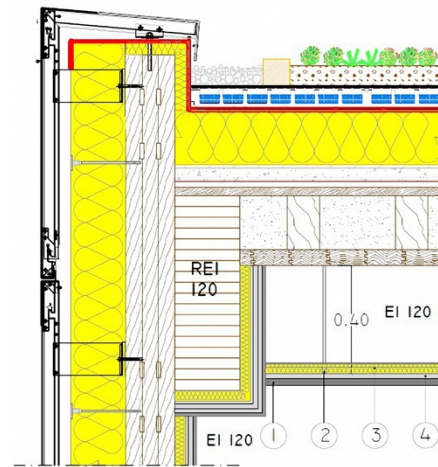
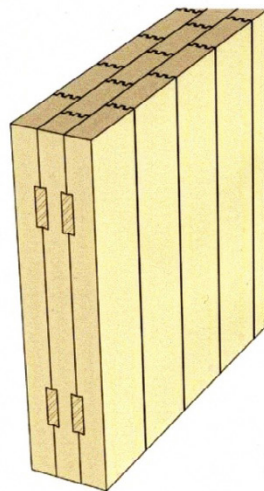
Figure 9 | Second floor plan.

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 (Fig. 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 - S1 non a vista - NSI
Essenze legnose per lo strato a vista:	abete rosso (F1) cirmolo (Z1) altre essenze a richiesta
Essenze legnose per i rimanenti strati	abete rosso (F1) cirmolo (Z1)
Umidità del legno:	14% +/- 2%
Tenuta all'aria:	si
Misure dell'elemento:	lunghezza ≤ 5 m/altezza ≤ 3 m lunghezza ≤ 2,95 m/altezza ≤ 6 m
Peso specifico:	480 kg/m ³
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

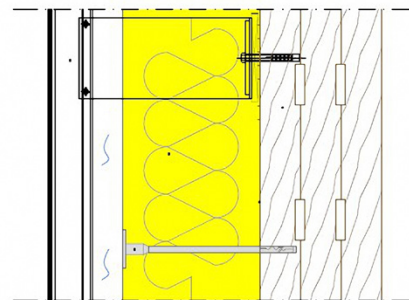


Figure 10 | Perimeter walls in Soligno®180 panels: data sheet, construction detail of the roof, current vertical section on Alucobond ventilated rainscreen.

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 (Fig. 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/m²K. 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®.

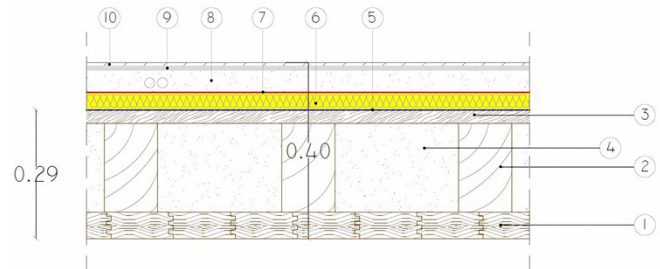
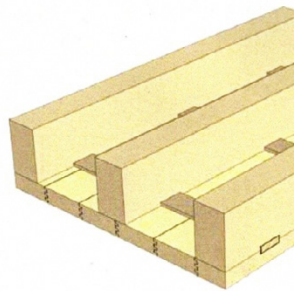
4. Post-tension and passive dissipation system for the central part of the building

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 (Fig. 12, 16 and 18). It has until now used only for



Dati identificativi del prodotto

Applicazioni:	solai scantinato solai piani solai mezzanino elementi per tetti
Spessore dell'elemento:	260 mm
Composizione:	copertura 60 mm travatura 120 x 160 mm
Tipo di solai:	soligno® 260/30 - 100
Qualità:	a vista = S1 non a vista = NS1
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.

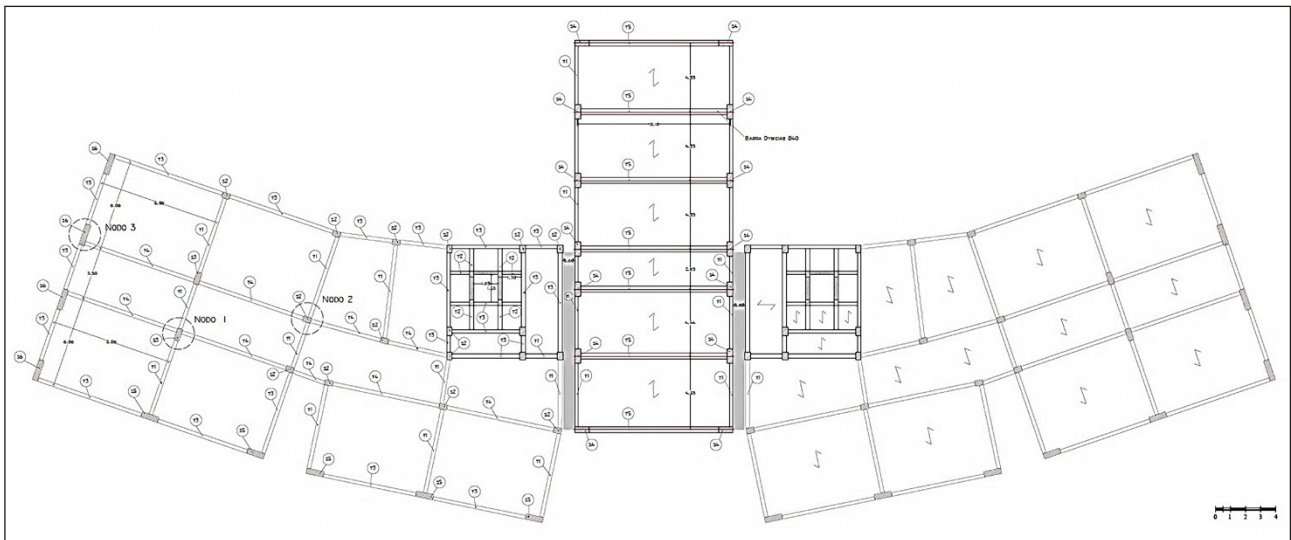


Figure 12 | Structural plan of the first floor.

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

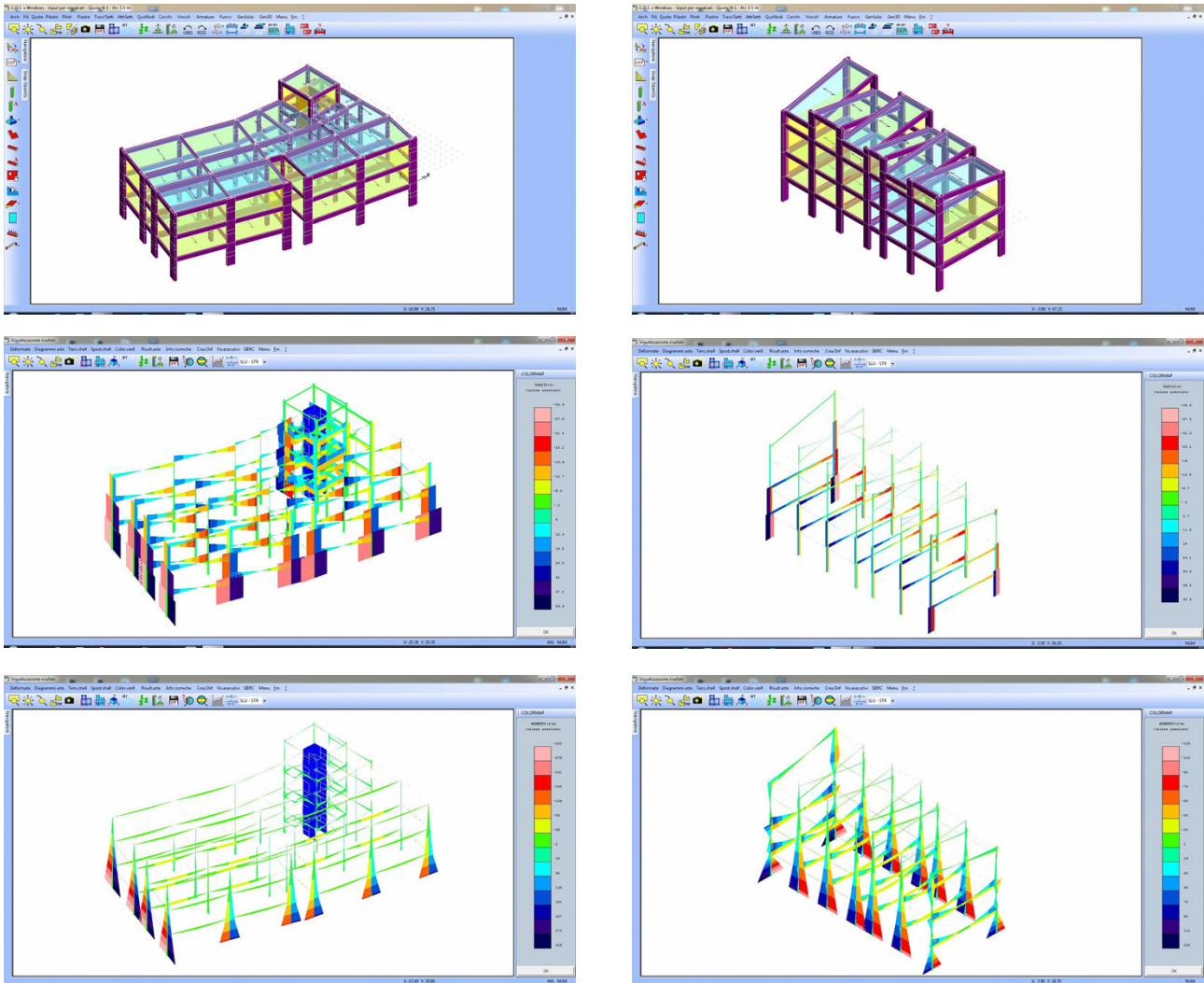


Figure 13 | Modelling of the structure and envelope of combination of bending moment and shear stresses, both of the West wing body (left) and of the central part of the building (right).

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 Ernő 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

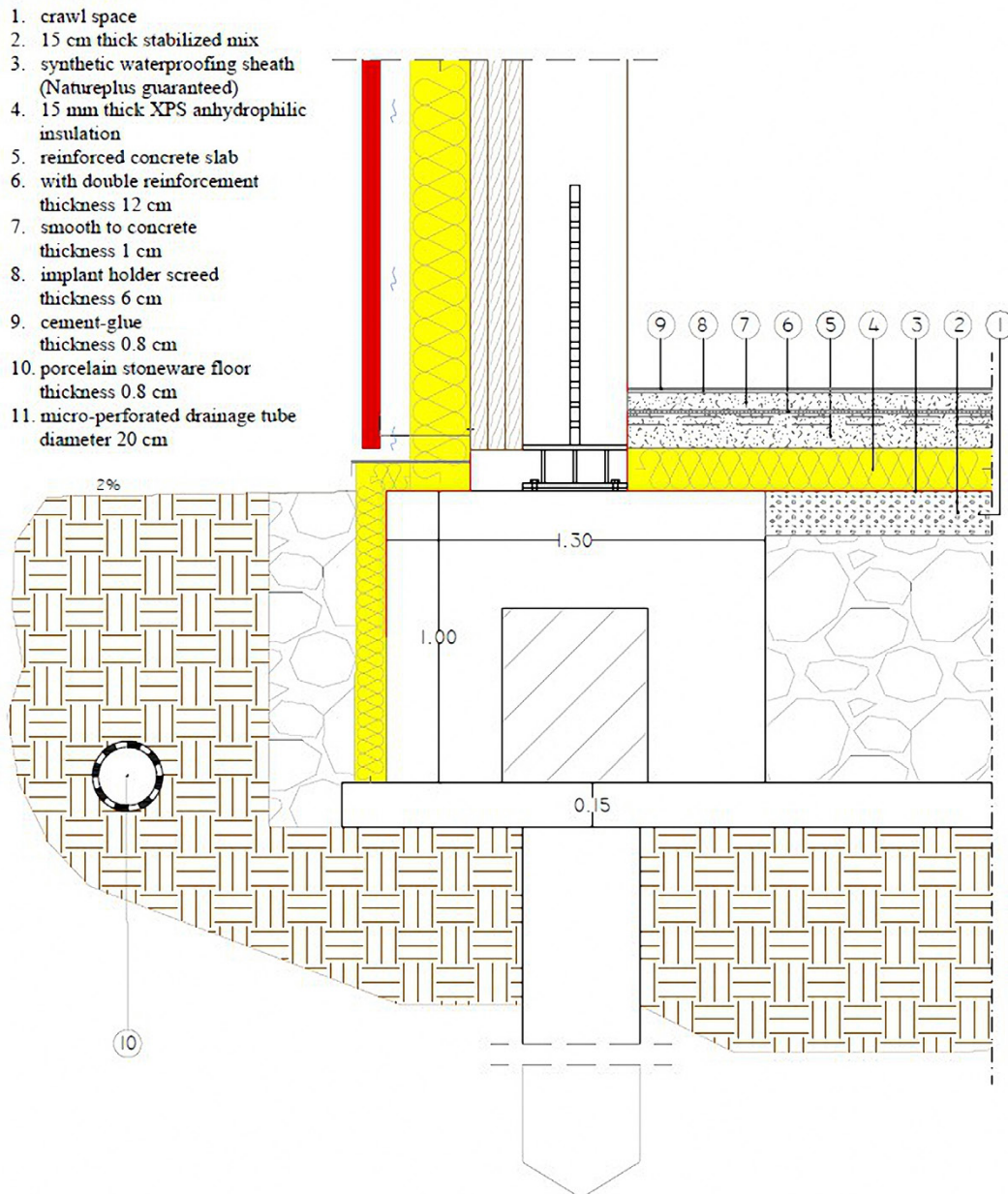


Figure 14 | Detail of the ground connection.

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-Himmel(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).

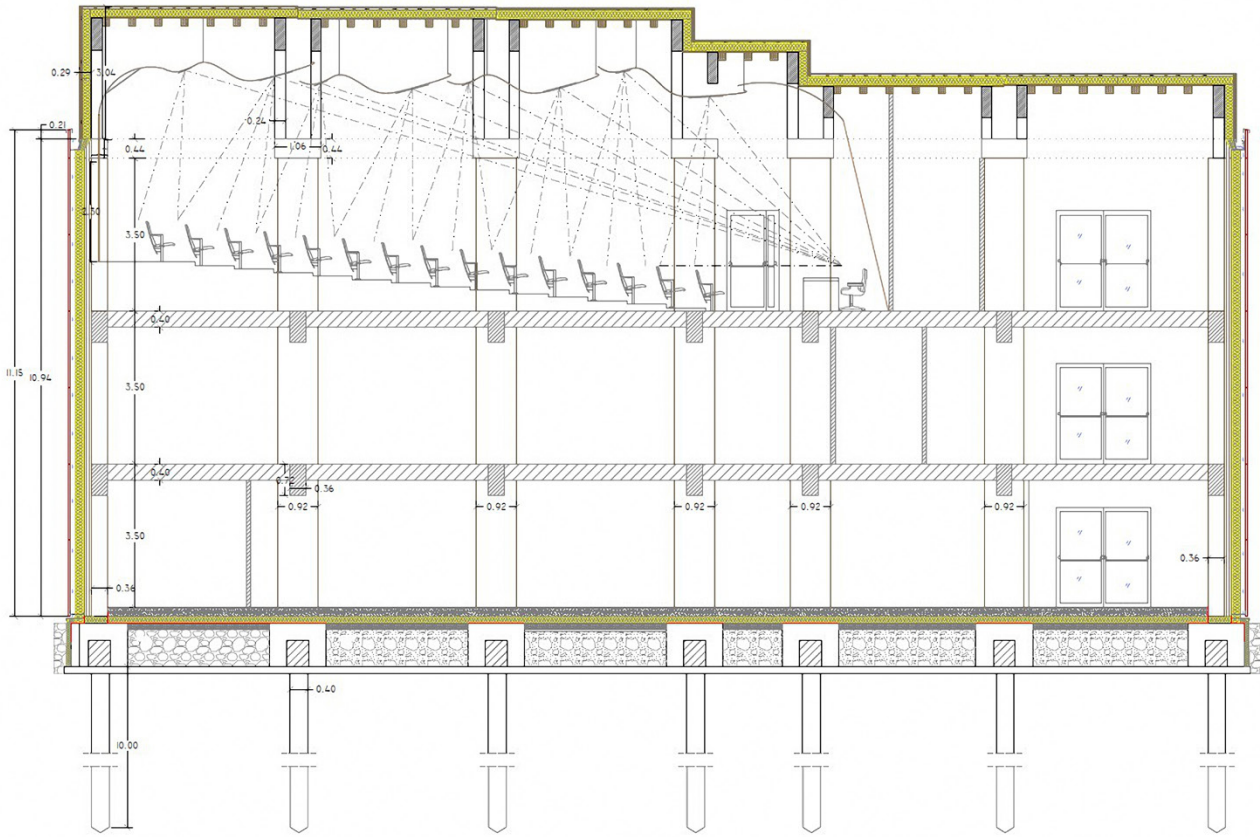


Figure 15 | Cross section on the central part.

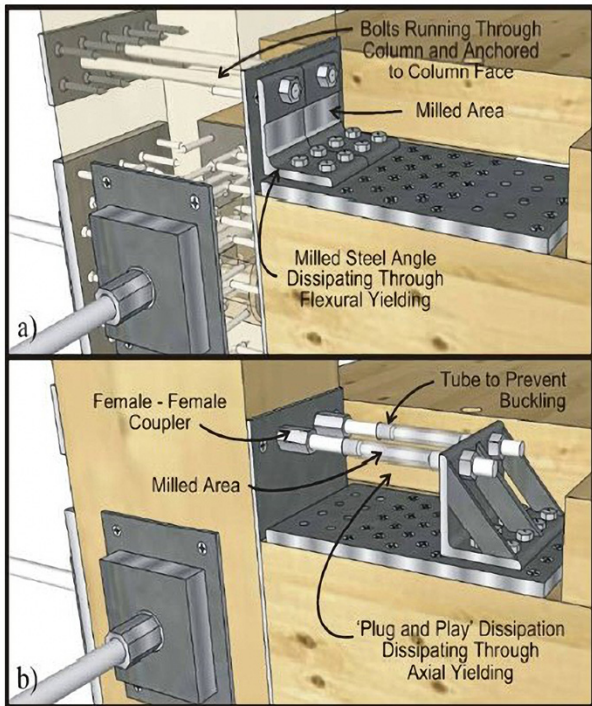


Figure 16 | Two dissipation methods that can be applied to the PRES-LAM Post-Compression system: a) the angle bars in yieldable steel; b) the axial device called "plug and play".



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

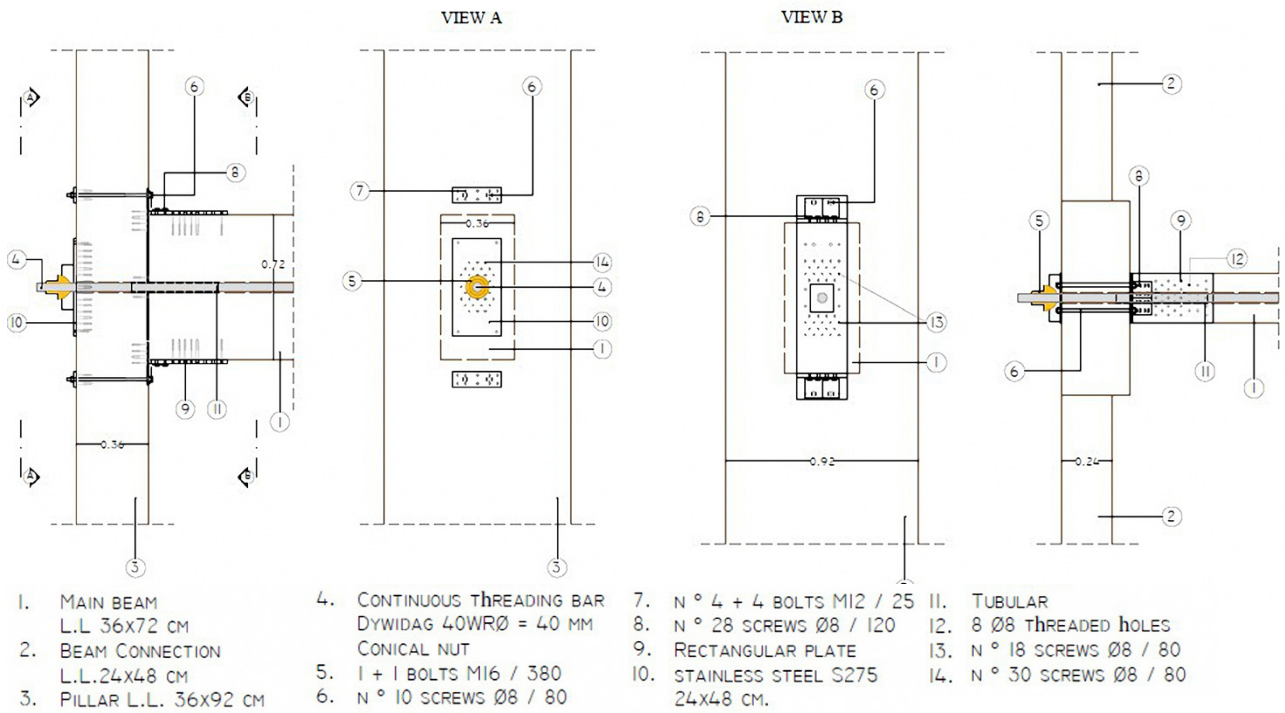


Figure 18 | Detail of the Pres-Lam System node.

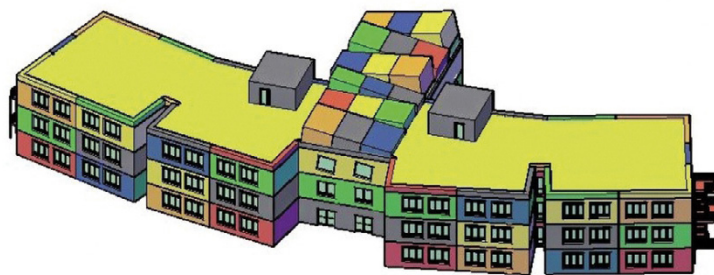


Figure 19 | Axonometric South view of the school.

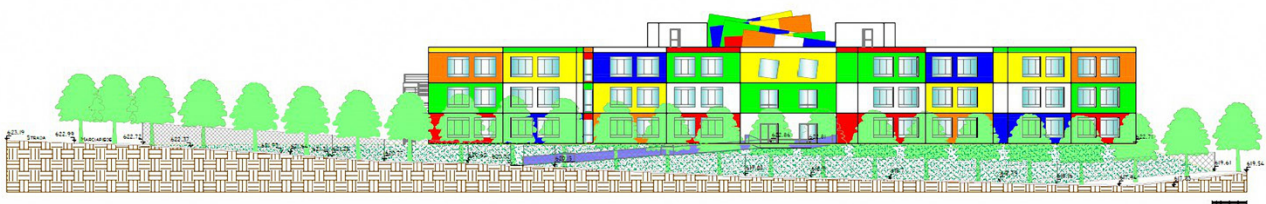


Figure 20 | View of the main elevation facing South.

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.

CO₂ 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.

It has been foreseen that the energy needed by the school is provided by 350 *Sony* photovoltaic panels, for 483 m² 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

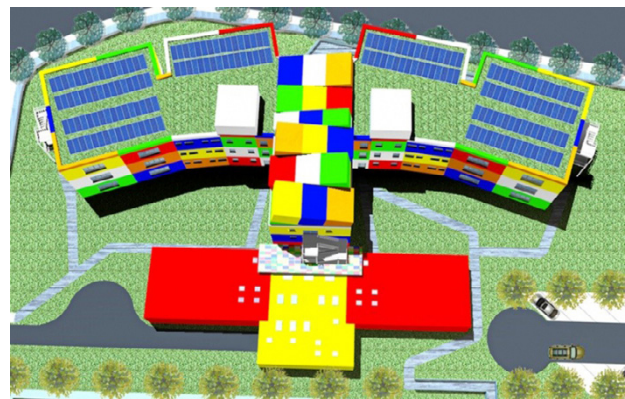
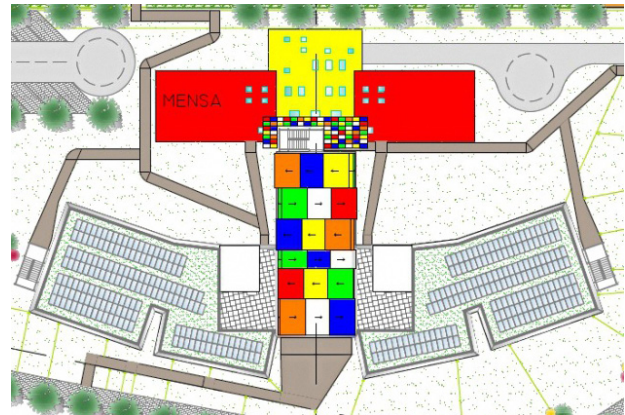


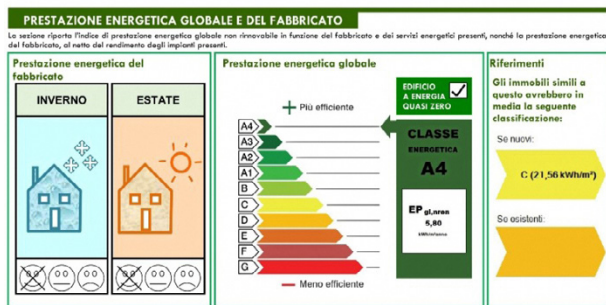
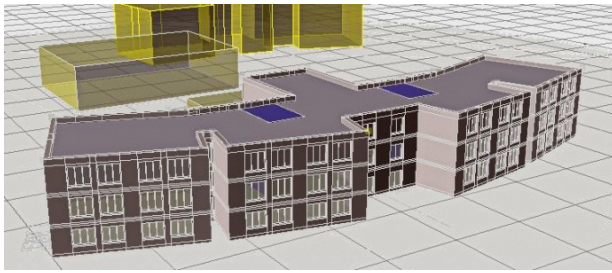
Figure 21 | Plan and 3d photorealistic view with location of the photovoltaic and solar thermal panels.



Figure 22 | Overall 3d photorealistic view.

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 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 annuali di energia

FONTE ENERGETICHE UTILIZZATE	Quantità annua consumata in uso standard (specificare unità di misura)	Indici di prestazione energetica globale ed emissioni
<input checked="" type="checkbox"/> Energia elettrica da rete	11300 kWh	Indice della prestazione energetica non rinnovabile EP _{gl,nren} kWh/m² anno 5,80
<input type="checkbox"/> Gas naturale		
<input type="checkbox"/> GPL		Indice della prestazione energetica rinnovabile EP _{gl,ren} kWh/m² anno 17,95
<input type="checkbox"/> Carbone		
<input type="checkbox"/> Gasolio e olio combustibile		Emissioni di CO ₂ kg/m² anno 0,9
<input type="checkbox"/> Biomasse solide		
<input type="checkbox"/> Biomasse liquide		
<input type="checkbox"/> Biomasse gassose		
<input checked="" type="checkbox"/> Solare fotovoltaico	122878 kWh	
<input checked="" type="checkbox"/> Solare termico	1990 kWh	
<input checked="" type="checkbox"/> Teleriscaldamento	19558 kWh	
<input type="checkbox"/> Teleraffrescamento		
<input type="checkbox"/> 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 m³, with a useful surface of 3,700 m² and a dispersing surface of 2,046 m², showed a *non-renewable global energy performance index* EP_{gl, nren} = 5.40 kWh/m² per year, that places the building in the best performing

category of Italian standard, A4 nZEB, with a CO₂ consumption of 0.9 kg/m² 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.

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