How to Refurbish ‘80s *Brutalist Architecture*, Turning It into NZEB: The Case Study of the High School “Enrico Fermi” in Muro Lucano (Potenza, Italy)

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Abstract The brutalist *architecture* of the ‘70s and ‘80s has the responsibility to have promoted the creation of buildings that, to better adhere to the poetics of exposed concrete, have often overlooked any principle of environment-Friendly quality. Many buildings, as this case study, a school built after the 1980s earthquake in Basilicata, as USAID gift, in Paul Rudolph’s style, have the exterior walls made in exposed concrete, without any type of insulation and lacking of flashings, but of downpipe too, so as to resemble, now, a picturesque ruin; have roofing systems wrongly designed; windows partly insufficiently sized to ensure natural lighting, but partly without any protection against dazzling; internal walls not performing acoustic performances fixed by Standards, and all grater spaces (atrium and corridors, auditorium, sports hall) with reverberation time many times the standard value. The building envelope disperses 50 kWh/m^3 year, so to be placed in the worst performance classes of actual Italian thermal rules. Becoming the conditions of use and management increasingly heavy and almost unbearable, this study detected the strategies and solutions by means of which to resolve the design faults, transforming the building in a NZEB eco-Friend, which produces from renewable sources the energy required for its necessities, recovering its original appearance and formal configuration.

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1 Introduction

On the evening of November 23, 1980, an earthquake of magnitude 6.9 on the Richter scale struck the Campania and Basilicata regions, causing more than 2,900 deaths, 8,850 injuries and more than 280,000 homeless. Among the Government Agencies that moved more decisively to bring aid to people affected by the earthquake, it was the *United States Agency for International Development* (USAID): the United States Congress appropriated a total of more than $70 million, of which $51.4 million were used in the design and construction or re-construction of 28 school buildings in 12 municipalities in the Campania and Basilicata regions, to be reconstructed in a maximum of 45 months. In Basilicata, the school buildings were identified in 3 municipalities: Picerno (Higher Technical Institute "Albert Einstein") [1]; Muro Lucano (Scientific High School "Enrico Fermi", examined in this report); Rionero in Vulture (Institute Of Higher Education "Giustino Fortunato") [2]. The three buildings designed at the same time and by the same *équipe* (Interplan Design Studio of Naples, professor's architects Alberto Izzo and Camillo Gubitosi, in cooperation with the firm Blurock Partnership, Newport Beach, California) and realized, after public contract, by the same enterprise, have the same characteristics and the same defects and suffer from the same pathologies.

2 Research Subject

The school of Muro Lucano is located in a large plot of 17,350 m^2, 2.5 km from the city center, in an area with average gradient of 30 % to the South, and then very sunny, with an altimetry variable between 580 and 610 m above sea level. From the typological point of view, the building follows a "plate" and "functional units" scheme. The building, which has a total net area of 3,383 m^2, has two floors in the South (normal classrooms and library) (see Photo 1) and one in the North (Gym and special classrooms for labs) (see Photos 2 and 3) (under which, there is a basement, dug but

Photo 1 View of South elevation

Photo 2 Northern view of the Gym

Photo 3 Exterior view of the laboratories

not used). In the center, a double-height atrium-corridor creates a Le Corbusier's *promenade architéctonique*, involving the library in the din of the hall (see Photos 4, 5 and 6).

The volumetric approach is unequivocally inspired by the '60s architecture of Paul Rudolph, in heavy overhangs projections and sculpted openings, with windows backward from the line of façades.

These are the years in which the *brutalism* goes so out of fashion, by pushing designers to propose exposed concrete surfaces both inside and outside, thereby not complying with the rules, while existing at the time, about the risk of condensation related to thermal bridges and energy consumption (U from 2.74 to 3.06 and up to 3.43 W/m^2 K, leakage through the envelope 50 kWh/m^3); the reverberation time (more than 8 s in the Gym, 2 s in the hallway of classrooms, 1.5 s in the Great Hall and in the teachers' lounge) (see Fig. 1); the natural lighting of the rooms (average daylight factor $\eta = 3$ % required by the standard; 0.89 in the multimedia lab, in the physics

Photo 4 Exterior view of the atrium-library

Photo 5 Internal view of the atrium-library

Photo 6 Internal view of the *upper* atrium

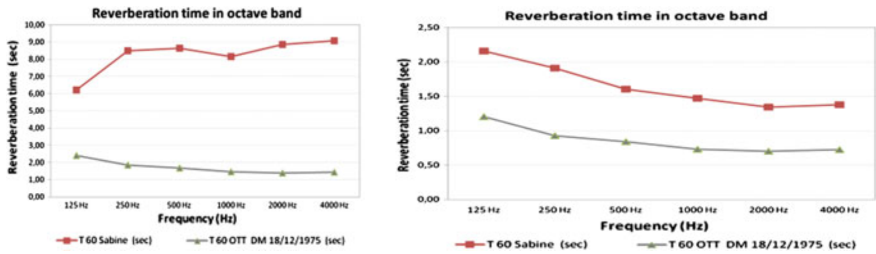

Fig. 1 Reverberation time in the Gym (*left*) and teachers' lounge (*right*)

Photo 7 The dripping of water from the rainspouts

laboratory and in the classrooms IB, IIA and IIB; 1.07 in drawing laboratory; 1.48 in the computer lab and science-Great Hall, but, conversely, $\eta = 7.63$ in the atrium, 6.56 in the hallway, 5.27 in the living room of the guardian, 3.47 in the deposits of the gym and 4.03 in the classrooms on the first floor). In each device, such as covers, downspouts, window sills, the correct "rules of art" have been neglected. So, for example, it depends on not following correct "rules of art" the fact of forgetting to put a vapor barrier under slabs of the slopes in coverage ($U = 0.74\ W/m^2\ K$), so that those that appear as stains moisture from rain water in some places are also stains moisture from condensation; ensuring that, to the North, the building is black, becoming covered in mold corresponding to the areas where the water is concentrated and drip free from the rainspouts placed several meters in height (see Photo 7); making sure that the flat coverings become "lagoons" for the failure of the slopes or occlusion of the rainspouts

Photo 8 Water-logging on the caretaker's apartment

Photo 9 Slab propped up with steel beams

(see Photo 8); ensuring that the insufficient reinforcement concrete cover of the not-visible structures (bottom intrados of the floor, to the basement not used) compromises their stability so as to make it necessary for them to shoring (see Photo 9).

And yet, the school room have the same endowment of windows facing South, with an unobstructed view of the sky, and those facing North, with tall trees nearby and the slope of the hill looming, which limits the visible portion of the sky (reprehensible, to have set special classrooms and laboratory spaces facing North, precisely because they require greater illumination than the normal classrooms). The lack of any device for the elimination of glare, forces on the south side, students and teachers, to stick on the windows newspapers or sheets of black plastic and, on the north side, condemns them to remain in a state of gloom.

Similar negative evaluations are those that relate to the natural and artificial ventilation of the rooms of the school. Natural ventilation (for permeability of the fixtures and their openness) is low, due to the widespread use of sliding and/or fixed doors. The mechanical ventilation works only in the Gym, while in the classrooms has been irreparably damaged by vandalism. All this, in a building less than 30 years ago, and despite the clear indications in the legislation for school construction (Ministerial Decree of 18 December 1975 n.18): effect of design errors obviously and easily avoidable, as proof of what often cited in the literature about the impact of the errors on the total design of the causes of pathologies [3].

3 Aim and Content of the Research

A specific method of refurbishment and technological (in particular thermal) upgrade has been identified and such as to be used in all cases of "brutalist" architecture, that in the city of Potenza and its province counts several schools, a psychiatric hospital, and the Court: these buildings, to a greater or lesser extent, have the same problems under examination. The constraint was to obtain a formal result that would preserve the values of the textural image of the building, innovating it only in order to consider the different cultural climate of today, more sensible to the typological importance of the colour and to its content of communication.

The study started with a careful consideration of site environmental data and the orientation of the building. Muro Lucano is located at latitude 40°45′12″60 N, longitude 15°29′11″76 E, 600 m osl, 2,000 degree-days, Climatic Zone D, "*Csa*" according to the classification of W. Koppen ("*sub-continental temperate*" "*wet summer with very hot* (T > 22 °C) *dry*"), even according to the ENEA "$3F_1$", which brings comfortable 3 months, and more than 6 months cold or very cold. The two hottest months are July and August, with average monthly temperature of 23.4 °C. The coldest months are January (5.1 °C) and February (5.8 °C), followed by December (6.7 °C) and March (8.3 °C). The monthly average outdoor relative humidity is very high: 75.6 % in January, 73.8 % in February, 67.5 % in March, up to a minimum of 59.9 % in August, before rising to 68.5 % in September, gradually increasing up to 78.7 % in December. And it is the average relative humidity: in fact, in the winter months it is not uncommon to encounter, for several consecutive days, an outdoor relative humidity greater than 90 %. This means that if a natural air exchange is carried out, the "clean" air introduced is more humid than air expelled, and the risk of surface and interstitial condensation proportionally increase. The prevailing wind direction is from 240° West-South/West, and the annual average speed of 3.80 m/s. The average annual rainfall is between 600 and 750 mm; analysis of solar irradiation was performed with *Autodesk Ecotect Analysis*, and were built shading masks for all the major surfaces of the façades and roof of building (also expecting to use for the installation of photovoltaic panels), through which, among other things, it has been found that the outdoor theatre on the North side is in the shade for most of the year, except from 10.30 to 16.00 approximately, from March to October. This is the obvious reason that made it unused and abandoned.

After verifying that the *seismic vulnerability* of the building meets the current Italian regulations, the first intervention involved the review of all the surfaces of exposed concrete deteriorated for carbonation, through the application of a comprehensive care cycle *Sto Cretec* type. The use of parts of the ground excavated, but not used, on the front of the North, was then expected: the places were lit and, for the purposes of fire safety, made accessible through the implementation of an overdraft basement corridor, 2.60 m wide and with two emergency staircases. The destination of these spaces is of Chemistry and Physics laboratories, with its stores, changing rooms and toilets. Their natural lighting, and that of many other parts of the building, including the Great Hall, has been optimized through the provision of *solar tubes*, starting from the coverage of the floor above (see Figs. 2 and 3). The Gym and drawing and computer laboratories located above those already mentioned, were instead provided with sheds, and arranged with openings windows facing north and with the roof surface covered with photovoltaic panels (see Fig. 4).

The building envelope was brought to performance similar to those of a "passive house", applying 12 cm of EPS with expanded graphite, with a synthetic plaster coats, sandpapered and washed with bark effect, lead-gray, very similar to a concrete-face view, water-repellent, self-cleaning. The volume of the Gym, which is separate from the main building, is colored differently with a particular tone green grass. The windows were doubled with others, also in aluminum and with sliding, but in thermal cutting and high performance, and in the space between the two windows was placed a blind, creating a *Double Skin Façade* [4], and thereby all the problems of glare and overheating resolving, if any. The U transmittance of the external walls becomes 0.192 W/m^2 K, the phase shift becomes 12.42 h and the thermal bridges are all eliminated. Similarly it is obtained for roofs, on which is

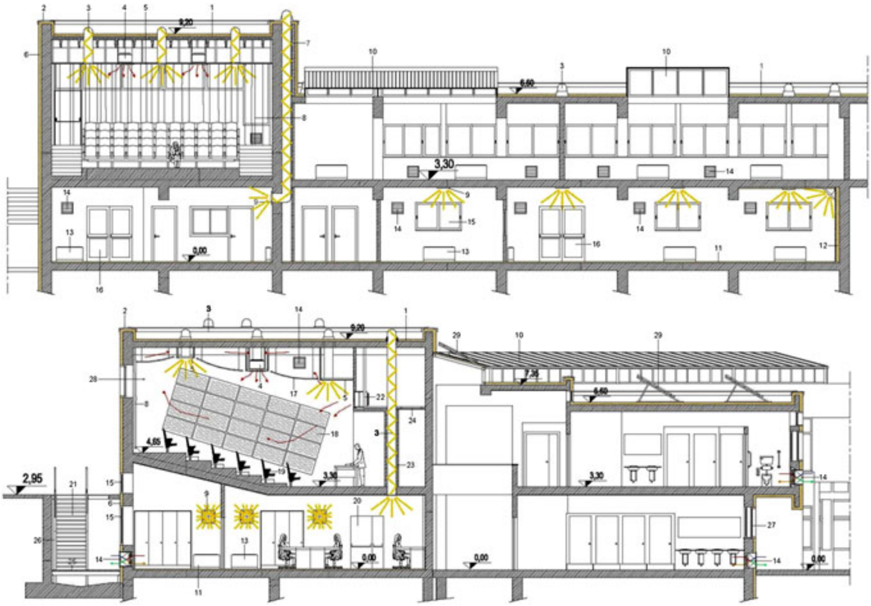

Fig. 2 Natural lighting with solar tubes and acoustical devices of Great Hall

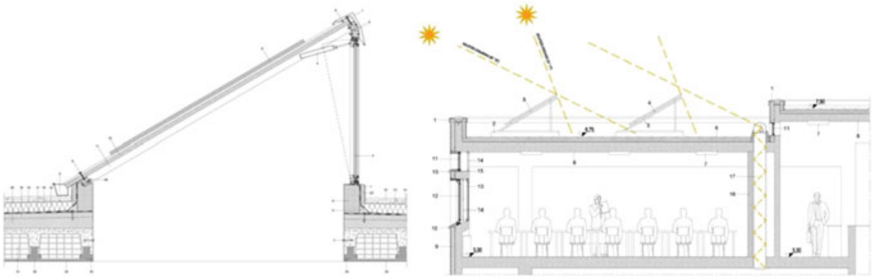

Fig. 3 Natural lighting (shed with PV panels on the roof) optimized through the provision of solar tubes

Fig. 4 Overall external view South-East side shows the different color finishes of the main building envelope and Gym, and the placement of photovoltaic panels on the roof of the sheds

applied an “inverted roof ventilated” XPS 10 cm, with semi-rigid PVC circular spacers and above FRC white tiles, with U = 0.167 W/m^2 K and phase shift of 17.72 h. The problems of lack of sound insulation between classrooms and corridors, due to the wrong choice of design components, are treated with the application of additional sheets of drywall, with different surface mass, and soundproofing mats in the cavities. The problems of higher value of reverberation time in the Gym are solved with the application on the walls (most exposed to footballs), up to 3.10 m height, of RMIG panels 42 mm thick, coated with 5/10 mm perforated aluminium and internal mineral wool, with excellent sound absorbing power, especially at medium and high frequencies. The solution provided for the ceilings is to coat them with sound-absorbing panels of mineral wool, 40 mm thick, glued directly beneath the beams to TT slabs, with the result of bringing the reverberation time T_{60} well below the standard value, between 1.50 and 1 s, depending on the octave band considered.

The problem of noise and excessive reverberation time in the hall/library/hallway is solved through the division of the space of the library from the atrium and the corridor through a structural glass, screen-printed with photos of Enrico Fermi, which enables to maintain the visual unity of space, intervening only on the propagation of noise. This solution is here laid on the ceiling and on the walls: on the first, placing a new false ceiling in mineral wool panels 1.5 cm thick; on the latter, through counter-walls containing mineral wool panels 27 mm thick, consisting of granulated recycled glass panels with surface coating of aluminium. In some places, the attachment of additional sound-absorbing panels is provided with screen prints of works by Keith Haring (see Fig. 5). A careful study of the colours makes the surfaces lively and interesting and better defines the geometry (see Fig. 6).

Similar solution has been designed for the Great Hall (in Fig. 2), which is currently used as Natural Science Laboratory. The intervention involves the use of: (1) sound-absorbing panels on the ceiling of mineral wool thickness of 3.2 cm, suspended with adjustable tie-rods; (2) granulated recycled glass panels, and (3) wooden perforated acoustic panels on the walls.

The reverberation time T_{60} becomes equal to 0.5 s at all frequencies, well below what is required by the Standard. The substitution of devices for mechanical controlled ventilation, with heat recovery, where damaged, is scheduled, and their installation in the new laboratories. The replacement of a part of the fan-coils, now out of service, has been foreseen, as well as the replacement of the generator to condensation with two new heat pumps of the type "water-water", allowing the complex building-plant to reach energy efficency Class A+. On covers, rehabilitated and isolated, the placement of solar panels until the exhaustion of the free surfaces sunny, is planned for a power of 61.5 kW.

Fig. 5 Overall internal view of the atrium with acoustic panels steel coated

Fig. 6 Overall internal view of the atrium: it is evident the careful study of color which makes the surfaces lively and interesting and better defines the geometry

4 Conclusions

In summary, the following results were obtained:

- the building, as restored, is in energy Class A+, with an Epi equal to 5.2 kWh/m^3 year [5]. As demonstrated in other studies [6], the savings generated by the intervention allow us to have a payback period of about 15 years;
- the useful life of the building changes from 90 to 120 years;
- the market value of the building increases;
- the intervention is advantageous, and above all, perfectly compatible with the conservation of the formal characteristics of the building, expression of the relevant international architectural culture of the ‘80s.

Contributions The contribution of the authors in the research and in editing and writing the text of the paper, was equal.

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