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Functional, energy and seismic retrofitting in existing building: an innovative system based on xlam technology

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Abstract

In recent years significant investments were made in retrofitting of existing buildings with the aim to realize a strong functional, energy and seismic refurbishment. This is a complicated challenge: the technical and economic feasibility of intervention must be correctly defined and most of interventions are not standardized or coordinated or properly managed.

Given the awareness related to environmental sustainability topics, this study focused on the development of systems and technologies based on the use of natural and environmentally sustainable materials.

The paper is focused on the xlam panel that is integrated into an existing building (outside or inside the external wall) in order to improve the static and structural tightening. The system is designed for modularization and standardization for giving simplicity and speed of assembly and low cost providing also.

Through a three-dimensional and numerical model, simulations were carried out to verify and to optimize the energy behavior of the chosen materials and to identify the best combination on thermal performance compared with the costs and environmental impacts of the product. The values and the results obtained were tested experimentally in the laboratory by the construction of a prototype.

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1. Introduction

In Italy existing buildings are totally inappropriate in earthquake case as seen in recent seismic events (Molise in 2002, L'Aquila in 2009, Emilia in 2012); in fact 82% of Italian residential stock was built before 1980 but the first legislation that imposes technical criteria of anti-seismic construction was enacted on 2003, and moreover the first national law about energy saving was enacted in 1976, because there were low cost of energy providing and no awareness about environment or climate change. So actually in Italy 13 million of building need a strong energy and seismic refurbishment. The research develops and deepens the application of a particular structural xlam panel connected to existing masonry: wood in fact has excellent characteristics such as light weight, mechanical strength and thermal insulation; as well xlam technology has demonstrated the capacity on stress distribution both in the vertical than in horizontal direction even in the presence of openings. A Xlam panel shows a great ratio between strength and specific weight compared to other common materials such as masonry or concrete and also it presents a better hard-set and anti-seismic behavior than a wood frame structure. The proposed technological system is composed as follows: a metal structure is fixed at the slab level or in the existent masonry for providing flexural rigidity and it's connected to Xlam panel by wood curb which transfers shear stresses coming from the building. The different kind of insulating materials have been proposed in order to improve the thermal resistance and to optimize the hygrometric behavior of the panel. This study focused also on the environmental impacts (Carbon Footprint and Embodied Energy) of each material and the economic feasibility was evaluated for the proposed combination of layers and products. The main objective is to identify the best combination that could be able to achieve all benchmarks of the research reducing energy consumption and lowering CO₂ emissions and being cost-effective.

2. Methodology

The research work was planned and followed a precise strategic line for checking the type of intervention and the performances of the technological component, applying on a single external wall and comparing all aspects of analysis. The first phase has seen the construction of a matrix (Table 1) in which elements were selected introducing a code for xlam (K), insulation (X), selected between the best sellers in market, and masonry (Y), selected on the schedule of the UNITS 11300-1; some specific characteristics have been identified to carry out the analysis: for example, values of thickness, thermal conductivity, specific heat, steam resistance, environmental impacts (LCA), supply and laying costs.

Table 1 - Elements

Description	code	name
 K xlam panel	K	Xlam Panel
	Ya	MP01 - Brick wall (Rif.A)
	Yb	CV01 - Masonry in perforated brick with cavity -1- (Rif.A)
 Y Existing wall	Yc	PF01 - Concrete wall (Rif. B)
	Yd	PF04 - Precast and insulated concrete wall -1- (Rif. B)
	Ye	CV01 - Masonry in perforated brick with cavity and insulation
	Yf	CO04 - Masonry in concrete blocks with cavity (Rif.B)
 X Insulation	X1	foam glass

- X2 extruded polystyrene foam (XPS)
- X3 expanded polystyrene (EPS)
- X4 wood fiber
- X5 mineral wool
- X6 aerogel
- X7 vacuum insulated panel (VIP)

Then four combinations of different stratigraphy of the various elements were identified; these combinations became the object of all analysis and simulations (Figure 1). Each combination is identified by the real possibility of intervention in an existent masonry building (see code Y in Table 1) and by adopting the technological system in Xlam. The Italian legislation on historic facades protection, the level of damage and decay of the building, the location and condition of the site at urban level affect the positioning of the panel (see code K in Table 1) outside or inside the existing masonry wall and, as consequence, the internal or external application of insulation (X).

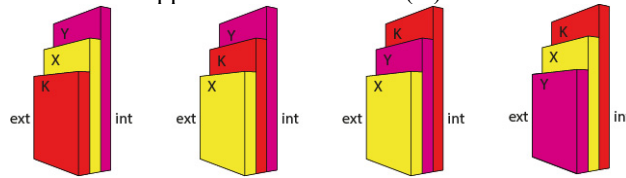


Figure 1 - Possible kind of combinations

The obtained combinations allow to understand what is the more favorable stratification between the various ones in the Italian building stock. It's also possible to control the performances of the intervention in an existing building.

3. Thermal analysis

Because of its fiber orientations and porosity, wood can be considered a poor heat conductor. Since the thermal conductivity (λ) dependent on the presence of air and water within the wood, the value is strongly tied to considered wooden species and establishing a percentage of moisture content of 20% values are fluctuating between 0.10 and 0.20 W/(mK). The masonry walls instead have different features because the stratigraphy is composed by different materials, age and manufacturing, and also it's influenced by the geographic area and the type of construction. However, the thermal properties values are obtained from the UNITS11300-1 database [1] which lists the most useful configurations and obtained thermal transmittance is a U value between 1.4 and 0.7 W/(m²K).

Table 2 - Minimum insulation thickness to achieve U = 0.34 W/m²K

		m for Ya wall	m for Yb wall	m for Yc wall
X1	foam glass	0,062	0,052	0,024
X2	extruded polystyrene foam (XPS)	0,054	0,045	0,020
X3	expanded polystyrene (EPS)	0,055	0,046	0, 21
X4	wood fiber	0,068	0,056	0,026
X5	mineral wool	0,068	0,056	0,026
X6	aerogel	0,021	0,017	0,008

X7 vacuum insulated panel (VIP)	0,010	0,008	0,002
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The proposed insulating materials are different because of their origin, vegetable, mineral, synthetic and composite. The main objective was to identify the thickness of each insulation for obtaining the minimum U values of the wall according to current national regulation [2] - 0.34 W/m²K for an Italian climate zone E corresponding to Venice area - and also that to obtain a lower thickness than the value of 0.1 m, corresponding to the interspace created by the metal structure for holding the Xlam panel up. The most important result is that all proposed insulations allow thickness below 0.07 m (Table 2). Examples concern a selection of masonry with the combination XKY, tested with all types of masonry and selected insulation. The second goal was the calculation of acceptable phase shift values which value shall be more than 12 hours. The study was carried out by applying the characteristics of the components on the same cases used for the transmittance and in the first analysis was calculated the minimum value of insulation thickness that is required to get at least 12 hours of phase shift (Table 3); results show the heat flux delay that was accumulated through the wall depending on the different stratigraphy and kind of masonry.

Table 3 - Thermal lag

	h for Ya wall	h for Yb wall	h for Yd wall	thickness for 12h time lag (m)
X1 foam glass	20,60	6,59	6,66	0,34
X2 extruded polystyrene foam (XPS)	19,82	5,82	5,88	0,43
X3 expanded polystyrene (EPS)	19,96	5,95	6,01	0,43
X4 wood fiber	22,85	8,8	8,84	0,23
X5 mineral wool	19,82	5,81	5,88	0,51
X6 aerogel	0,33	10,32	10,38	0,18
X7 vacuum insulated panel (VIP)	6,16	16,15	16,21	0,10

Finally, following the current legislation requirements, the formation of interstitial moisture on walls has been verified, specially into insulation layer. Outcomes demonstrate a null value moisture not for all layers, however the annual budget has always negative balance: the amount of evaporable water vapor is greater than the amount condensable, which must be less than the limit value (500 g/m²).

4. Environmental Impact

The goal was to investigate the impact of the elements in the Xlam technological panel. The analysis has been focused on various insulations selected (Y) so as to obtain the values of the Embodied Energy measured in MJ/kg (Table 4) and to identify those with less impact at equivalent transmittance [3].

Table 4 - Embodied Energy values for insulation

	thickness[m]	specific weight[kg/m ³]	weight[kg/m ²]	embodied energy [MJ*kg]	[MJ]
X1 - foam glass	0,15	150,00	22	27,00	595,59
X2 - XPS	0,10	35,00	4	109,20	393,44
X3 - EPS	0,10	37,00	4	101,50	386,60
X4 - wood fiber	0,12	150,00	18	20,00	352,94
X5 - mineral wool	0,12	100,00	12	16,80	197,65
X6 - aerogel	0,04	120,00	5	53,00	243,18

X7 - VIP 0,02 175,00 3 140,00 432,35

The same study was also conducted on the kinds of masonry (X) and on the xlam panel (672MJ).

Table 5 - Impact categories

Impact category		X1	X2	X3	X4	X5	X6	X7
Human health	DALY	4,27E-05	9,99E-06	5,21E-06	1,92E-05	2,15E-05	3,65E-06	1,06E-05
Ecosystem quality	PDF*m2*yr	5,70E+00	1,00E+00	3,93E-01	1,04E+01	2,61E+00	4,39E-01	1,03E+00
Climate change	kg CO2 eq	3,99E+01	2,14E+01	1,12E+01	1,97E+01	1,68E+01	2,61E+00	1,46E+01
Resources	MJ primary	6,29E+02	3,62E+02	3,43E+02	2,75E+02	2,23E+02	2,64E+02	3,77E+02

Therefore the insertion of the technological element in xlam with the insulation hypothesis provided an absolute value of Embodied Energy ranging between 700 and 1300 MJ.

Afterwards investigations have focused on wood panel and insulation for the calculation of LCA of all materials by software simulations: using the method Impact2002+v2.11 the four impact categories (Table 5) and their values have been obtained, including the Embodied Energy expressed in resources category.

Calculation has allowed a comparison of the results obtained for Embodied Energy using the ICE database and the results are reliable and comparable because the database of the University of Bath allows a tolerance of approximately ± 30%. Finally the value of CO₂ equivalent was derived indicating the extent of the GWP (Global Warming Potential) of greenhouse gases for each selected material (Table 6).

Table 6 - IPCC 2007 impacts

	X1	X2	X3	X4	X5	X6	X7
kg CO2 eq	42,178	38,972	13,255	20,842	17,830	3,370	16,606

A comparison between the production process of packages according to the method 2007 IPCC (Intergovernmental Panel on Climate Change) has been analyzed: an unit value is attributed on-base percentage to the material with higher CO₂ equivalent and the remaining values were get consequently. Some materials such as aerogels and expanded polystyrene have low impact since in the first case the material used is little amount, while the second has low harm values for global warming.

5. Conclusions - research results

In reference to what was defined in methodology and based on the data of the various analyzes, it is possible to order obtained information and make a summary to configure the kind of base panel.

Also economic feasibility was conducted to determine the cost of the intervention: elements were considered individually by the calculation of supply and laying costs for panel and insulations. Costs are approximated and depend on changes in the market and in the adoption of the price list of each region, but it's a fact that synthetic materials have lower costs than natural ones, while aerogel and vacuum insulation have not still competitive costs.

The best combination of existing masonry, xlam panel and insulation is given precisely by the latter variable; in fact these selected insulations have different properties and performances, so they impact in a different way with other component: xlam panel is given by structural calculation and its characteristics are broadly similar in the actual market, while the kind of masonry might change depending on the building. The choice has been made taking as objective the minimization of heat loss, environmental impacts and intervention costs (Table 7).

Table 7 - Outcomes for insulation after thermal, impact and economic analysis

	λ [W/(mK)]	ϕ [h]	supply [€/ m ³]	laying [€/ m ²]	EE [MJ]	CF [kgCO ₂ eq]
X1 - foam glass	0,050	20,6	650,00	95,00	595,59	42,18
X2 - XPS	0,035	19,82	190,00	36,00	393,44	38,97
X3 - EPS	0,035	19,96	110,00	39,00	386,60	13,25
X4 - wood fiber	0,040	22,85	175,00	25,00	352,94	20,84
X5 - mineral wool	0,040	19,82	150,00	70,00	197,65	17,83
X6 - aerogel	0,013	0,33	430,00	90,00	243,18	3,37
X7 - VIP	0,006	6,16	5550,00	100,00	432,35	16,60

A further constraint has been added due to the size of the structure for fixing the existing masonry and to the passage of system net: from the previous analysis it has made that it could take advantage of 10 cm of thickness on the gap in the inner side of the panel in correspondence of structure or exploit the external side with a gap of 10 cm at least for plumping thickness. The type of insulation that better meet the demands and benchmarks for minimizing thermal, economic and environmental is mineral wool (X5), then polyurethane foam (EPS) (X3): this selection was the basis for all further analysis of technology nodes and the types of masonry.

The matrix was verified in order to control the formation of moisture [4] and the heat flow in thermal bridges and to provide data to other areas of the research, or rather the design and sizing of the technological elements and functional conformations. It was made a 3D model of the all kind of masonry, obtaining performances to understand the best combination depending on the position of the insulation. The result leads to the concept of an external "coat" (KXY), which, in addition to isolate, allows the complete precast of the panel and a fast installation on site, with related economic benefits (Figure 2).

Cat.	Material	Thickness (m)	Res. Therm. (m ² K/W)	Res. Fatt.	Air. Eq. Thi. (m)	Density (kg/m ³)	Spec. Cal. (J/kgK)	Weight (kg/m ²)	Embodied Energy in MJ*kg	MJ
	external		0,04							
INT	plasterboard	0,02	0,02	20,00	0,30	1800	836,80	40	1,00	40,00
ISL	X5 / mineral wool	0,10	2,50	1,00	0,10	50	1046	10	16,80	168,00
XL M	xiam	0,10	0,77	50,00	5,00	500	1600	48	14,00	672,00
INA	slightly ventilated cavity	0,10	0,11	1,00	0,10	1	1004			
INT	plasterboard	0,02	0,02	20,00	0,40	1800	837	40	1,00	40,00
MUR	solid brick	0,25	0,32	15,00	3,75	1800	1000	450	2,86	1287,00
INT	plasterboard	0,02	0,03	10,00	0,20	1400	837	28	3,30	92,40
	inner	0,61	0,13							

Figure 2 - Combination 2 - X5KYa

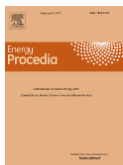
Finally a X5KYa prototype was built and verified with a "hotbox" test [5][6]: this stratigraphy has been chosen because it shows the worst values of temperature and humidity between those obtained with the combinations and with the selected materials, and also it has been studied since this type in fact it is the most widespread type of masonry in Italian building stock.

The research has achieved several objectives regarding the issues related to environmental and energy aspects: the technological component allows different solutions and assembly configurations, providing

with new windows and new heating and cooling systems; it was designed to reduce size and weight but always ensuring the minimum of the current regulations: the combinations matrix for insulation allows in fact comparable and applicable according to the type of existing buildings.

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Biography

Tiziano Dalla Mora. Actually he has a research grant at IUAV on near zero energy buildings. During his research and professional activity he gained experience on sustainable architecture design and building information modeling BIM. He worked on LEED certification following credits related to energy, light and indoor air quality and participation to the development of Historic Building Protocol by GBC Italia