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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 awarenessrelatedto environmental sustainability topics, this studyfocusedon the developmentof systems andtechnologiesbased on the useof 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 behaviorof the chosenmaterials and to identifythe best combinationon thermal performancecomparedwith the costsandenvironmental impactsof the product. The valuesand the results obtainedwere testedexperimentallyin the laboratoryby the constructionof a prototype.

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"Keyword: xlam system, prefabrication, sustainability, building physics and energy retrofitting, numerical simulation"

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1. Introduction

In Italy existing buildings are totallyinappropriatein earthquake case as seen in recent seismic events (Molise in 2002, L'Aquila in 2009, Emilia in 2012); infact 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 an strong energy and seismic refurbishment.The research develops anddeepensthe application of aparticularstructural 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 showsa great ratio between strength and specific weight compared to othercommon materialssuch as masonry or concrete and also it presents a better hard-set and anti-seismic behavior than a wood frame structure.The proposedtechnological systemis 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 woodencurb which transfers shear stresses coming from thebuilding.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 andthe 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 CO_2 emissions and being cost-effective.

2. Methodology

The research workwas planned andfollowed aprecisestrategic line for checking thetype of interventionand the performancesof the technological component, applying on a singleexternal walland comparingall aspectsof analysis.The first phasehas seenthe construction of amatrix(Table 1) in whichelementswere selected introducing a code for xlam(K), insulation(X), selected between the best sellers inmarket, andmasonry(Y), selected on the scheduleof the UNITS11300-1; some specific characteristicshave been identifiedtocarry out the analysis: for example,valuesofthickness, 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
Y Existing wall	Ya	MP01 - Brick wall (Rif.A)
	Yb	CV01 - Masonry in perforated brick with cavity -1- (Rif.A)
	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 stratigraphyof the various elementswereidentified; these combinationsbecamethe object ofall analysisand simulations(Figure 1). Each combinationis identifiedby thereal possibilityof interventionin an existent masonry building(see code Y in Table 1) and by adoptingthe technological systeminXlam.The Italian legislationon historic facades protection, the level ofdamage and decayof the building, the location andconditionof the site at urban levelaffect thepositioning of the panel(see code K in Table 1) outside or insidethe existing masonrywall and, as consequence, the internal or externalapplication of insulation(X).

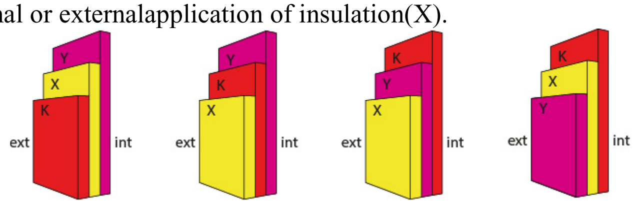


Figure 1 - Possible kind of combinations

The obtained combinationsallow to understand what is the more favorable stratification between the various ones in the Italian building stock. It's also possible to controlthe 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 consideredwooden species and establishing a percentage of moisture content of 20% values are fluctuating between 0.10 and 0.20 W/(mK).Themasonry wallsinsteadhave different featuresbecause the stratigraphy is composedby different materials, age andmanufacturing, and also it's influenced by the geographic areaand thetype of construction. However,the thermal properties values are obtainedfrom the UNITS11300-1 database [1]which lists the most usefulconfigurationsand obtained thermal transmittance isa U valuebetween 1.4and0.7W/(m^2K).

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

The proposed insulating materialsaredifferentbecause of theirorigin, vegetable, mineral, syntheticandcomposite.The main objectivewas toidentifythe thickness of eachinsulation for obtaining the minimum U values of the wallaccording to current national regulation [2] - 0.34W/m2K fora Italian climate zone E corresponding to Venice area - and also thatto obtain alower thicknessthan thevalueof 0.1m, correspondingto the interspacecreated by themetal structure for holding the xlam panel up. Themost important resultis thatall proposedinsulationallowthickness below0.07m(Table 2Table 2). Examplesconcerna selection ofmasonrywith the combination XKY, tested withalltypes ofmasonry andselectedinsulation.The second goalwas thecalculationofacceptablephase shiftvalueswhich value shall bemore than 12 hours.The study wascarried out by applyingthe characteristicsof the componentson the samecasesused forthe transmittanceandin the first analysiswas calculatedthe minimum value of insulationthicknessthat is required to getat least 12hours ofphase shift(Table 3): results showtheheat flux delay that was accumulatedthroughthewall 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, followingthe current legislation requirements, the formationofinterstitial moistureonwalls has been verified, specially into insulation layer. Outcomes demonstrate a null valuemoisturenotfor alllayers, however the annual budgethas alwaysnegative balance: the amount ofevaporablewater vaporis greater than the amountcondensable, which must be less than thelimit value(500 g/m²).

4. Environmental Impact

The goalwasto investigatethe impactof the elementsin thexlam technological panel. The analysis have been focusedon variousinsulatingselected(Y) so as to obtain the valuesof the Embodied Energymeasuredin MJ/kg(Table 4) andto identifythose withless impactat equalequivalent 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 studywas also conductedon the kinds ofmasonry(X) andon 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 insertionof the technological element in xlam with the insulation hypothesisprovidedan absolute valueofEmbodied Energy rangingbetween700and 1300MJ.

Afterwards investigationshave focused onwood paneland insulationfor thecalculation of LCAof all materials by software simulations: using the methodImpact2002+v2.11thefourimpact categories(Table 5) andtheir values have been obtained, including the Embodied Energyexpressed inresources category.

Calculation has allowed a comparison of the results obtained for Embodied Energy using the ICE database and the results are reliable and comparablebecause the database of the University of Bath allows a tolerance of approximately ± 30%.Finally the valueof CO_2 equivalent wasderived indicating the extentof theGWP(GlobalWarming Potential) of greenhouse gasesfor eachselected 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 theproduction processofpackagesaccording to the method2007 IPCC(Intergovernmental Panel on Climate Change) has been analyzed: an unit valueis attributedon-base percentageto the materialwithhigherCO_2equivalent and theremainingvalueswere get consequently. Some materials such asaerogelsand expanded polystyrenehavelowimpactssincein the first casethe material used islittle amount, while the secondhaslow harm values for global warming.

5. Conclusions - research results

Inreference to what wasdefinedin methodologyandbased on the dataof thevarious analyzes, it is possible to orderobtainedinformation and makea summaryto configure the kindofbase panel.

Also economic feasibilitywas conductedto determine thecost of the intervention: elementswere considered individually by the calculation of supply and laying costs for panel and insulations. Costsare approximated anddepend onchanges inthe market andin the adoptionof theprice listof each region, but it'sa factthat synthetic materialshavelower coststhan natural ones, whileaerogel and vacuum insulation havenotstillcompetitive 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 theyimpactin 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).

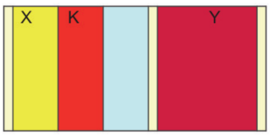
Table 7 - Outcomes for insulation after thermal, impact and economic analysis

	λ [W/(mK)]	φ [h]	supply [€/ m^3]	laying [€/ m^2]	EE [MJ]	CF [kgCO_2eq]
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 constrainthas added due to thesizeof the structureforfixingtheexisting masonryand tothe passage of system net: from the previousanalysisithasmadethat it couldtake advantage of10cm of thicknessonthe gapin theinner sideof the panel in correspondence of structureorexploit theexternalside with a gap of 10 cm at least forplumping thickness.The type ofinsulation thatbetter meet thedemandsand benchmarksfor minimizingthermal, economicandenvironmental is mineral wool(X5), thenpolyurethane foam(EPS) (X3): this selection was thebasisfor all furtheranalysis oftechnology nodesand the types ofmasonry.

Thenmatrix was verifiedinorder tocontrol the formationof moisture[4] and the heat flowinthermal bridgesand to provide datato otherareas of the research, or rather the design and sizing of the technological elements and functional conformations. It was made a 3D modelof the all kind of masonry, obtaining performances tounderstand thebest combinationdepending on the positionof the insulation.The resultleadsto the concept of an external"coat"(KXY), which, in addition to isolate,allows the completeprecastof the panel andafastinstallation on site, withrelated economic benefits (Figure 2).

Cat.	Material	Thickness (m)	Res.Therm. (m^2K/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
XLM	xlam	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							



U [W/m²K] 0,251
ϕ [h] 17,52
EE [MJ] 2299

Figure 2 - Combination 2 - X5KYa

Finally aX5KYa prototype was built and verified with a “hotbox” test [5][6]: this stratigraphy has been chosen because it showsthe worstvaluesoftemperatureand humiditybetweenthose obtainedwith the combinationsandwiththe selected materials, andalso it has been studiedsincethis typein fact it isthemost widespreadtype of masonryin 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.

References

[1] UNI TS 11300 - Normativa tecnica di riferimento sul risparmio energetico e la certificazione energetica degli edifici

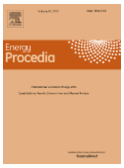
[2] D.Lgs.192/2005 e s.m. - Attuazione della direttiva 2002/91/CE relativa al rendimento energetico nell'edilizia

[3] ISO 140400 - Passaggi per lo sviluppo della procedura del Life Cycle Assessment

[4] UNI 13788:2003 - Prestazione igrotermica dei componenti e degli elementi per edilizia; verifica condensa interstiziale

[5] ASTM C-236, 1993. Standard Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a guarded Hot Box.

[6] UNI EN ISO 8990. Determinazione delle proprietà di trasmissione termica in regime stazionario: metodo della doppia camera calibrata e della doppia camera con anello di guardia.



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