VOLUMETRIC ADDITIONS FOR SUSTAINABLE REFURBISHMENT OF RESIDENTIAL BUILDINGS: FROM THEORY TO PRACTICE

Jacopo GASPARI
Department of Architecture, Alma Mater Studiorum University of Bologna, Italy, jacopo.gaspari@unibo.it

Ernesto ANTONINI
Department of Architecture, Alma Mater Studiorum University of Bologna, Italy, ernesto.antonini@unibo.it

Andrea BOERI
Department of Architecture, Alma Mater Studiorum University of Bologna, Italy, andrea.boeri@unibo.it

Danila LONGO
Department of Architecture, Alma Mater Studiorum University of Bologna, Italy, danila.longo@unibo.it

Summary

In the current negative economic climate, retrofitting and rationalization of the existing residential building stock represent a viable and strategic solution considering two key issues: the improvement of energy performance and the adaptation of the dimensions of the residential units to the emerging needs. The fast increase in households consisting of one or two persons and of five or more is a recognized social trend in most European countries, however more than half of the housing offer consists of flats of standard medium dimensions. Today, the energy demand of the existing housing stock largely exceeds the acceptable levels for sustainable consumption, therefore drastically increasing the relevant operation costs.

A research program, currently ongoing at the University of Bologna, Department of Architecture, is focusing on the analysis of the effects of volumetric additions to the existing housing stock, in terms of optimization of the units layout and the relevant energy performance. Starting from a theoretical matrix of strategies for volumetric addition, the research studied specific topics concerning the re-dimensioning of the flats, the increase in energy efficiency and the implementation of equipment on some case studies involving Italian residential buildings daring back from the ’60s to the ’90s.

This paper outlines the first results of a simulation of volumetric addition applied to different housing typologies located in different urban settings. Several refurbishment scenarios were performed, related to the densification level required. The volumetric additions were modelled in order to intensify the use of the built estate, broaden the range of the offer and feed a financial mechanism capable of generating resources that can be used for the building refurbishment.

Keywords: architectural addition, energy savings, densification, housing renewal

1 Background and starting position

1.1 Retrofitting for improving the quality of the existing building stock

The largest part of the building stock of most European cities was developed between the 60's and the early 90's when energy costs and a conscious approach to sustainable design were far from being key factors. Consequently, the existing building stock is affected by relevant technical obsolescence (both physical and functional) and a very high level of energy consumption (150–200 kWh/m^{2}y) [1]. Furthermore, large part of these buildings turned out to be unsuitable in meeting the needs of modern families and their changed lifestyle.

Within this framework, retrofitting and rationalization of this stock seems to be not only an unavoidable remedial measure to be adopted in the short term, but also a strategic choice in the long term. New investments to increase the housing offer don't seem to be realistic in the short term, given the persistent negative economic outlook. Therefore, retrofitting of the existing housing stock represents a viable solution to be implemented as fast and as often as possible, in order to maximize its efficiency and intensity of use, aiming at meeting the largest share of the emerging demand [2].

1.2 New demands and new trends

Several studies carried out on social housing stock in Europe allow to identify three main targets for retrofitting strategies, focusing on a reduction in operation and management costs, an improvement of the building capacity to meet the users' needs and an increase in the exploitation ratio of the assets:

- by adapting the housing typology, size and equipment in order to satisfy the emerging demand trends, pushed by a fast increase in households of one or two persons and of those of five or more, that the dimensions of the currently available medium size units cannot meet;
- by improving functionality and usability performances of the buildings – such as seismic safety, energy efficiency, comfort – with a related significant reduction in operating costs;
- by intensifying the utilization ratio of the built estate and increasing the settlement density, through the addition of new volumes intended both to expand the available housing offer and feed a financial mechanism capable of generating resources to be used for the building retrofitting.

A survey carried out on the European social housing sector [3,4] underlined that the densification of social housing blocks is a strategy widely adopted during the last two decades, mainly through the addition of new volumes, connected to the existing buildings in different ways, able to increase both the floor area and the functional and energy performance of the units, as well as of the whole building.

2 Refurbishment strategies and technological choices

A research program currently ongoing at the University of Bologna, Department of Architecture [5, 6], confirms the potential of the densification strategy and suggests a further study concerning some specific features of the refurbishment approach in order to

select the effective solutions for the transformation of the most widespread housing typology as in Europe as specifically in Italy. The study aims at testing several addition models where most of the benefits expected from the retrofitting action (additional floor area, additional equipment, implemented technical installation, improved envelope performance) are concentrated in the new added elements. The high level of adaptability and modulation is a further strength of the volumetric addition strategy in housing retrofitting: by adding volumes to the building original shape, an extended range of improved performances and new equipment can be implemented in a step by step process. So, the modifications can be easily related to the needs and the condition of both the building itself and the surrounding urban fabric, often gaining an effective integration and a good level of overall efficiency.

2.1 Addition models

Once selected several case-studies of volumetric addition in existing residential buildings from the large number of experiences yet available, the modalities of addition were classified in three main types [7], defined based on both geometric parameters and type of connection of the addition to the existing building. They were identified as follows:

- basement additions, mainly connected to building basement, ground floor and surrounding areas;
- façade additions, that can be realized through a cantilever system, or hooked to the building, or provided with an independent structure, spanning a large range of dimensions and configuration;
- rooftop additions, whose characteristics depend on the structural condition of the original building, as well as on the type and geometry of the existing roof.

By increasing the provision of living and service spaces, the addition can also improve the equipment supply and the level of usability, a performance particularly valued by the users, due to the poor standards of the existing units. Further benefits are related to the improvement of thermal and air tightness performance of the envelope and to the new image conferred to the building by the additions, as well as, in some cases, to the upgrading of the building structural behaviour.

2.2 Design criteria evaluation

Some important factors concerning the existing building had to be evaluated trough a multi-criteria approach before the morphological and technological characteristics of the addition could be defined.

- Step 01 – the structural analysis of the existing building, aiming at assessing its capacity to bear the application of the addition, with or without consolidation or reinforcement;
- Step 02 – the structural frame for the addition, according to its suitable size and position in relation to the existing building;
- Step 03 –the contribution of the addition to the thermal and energy behaviour of the building envelope. At the same time, the possibility to add passive and active devices for renewable energy can be explored;
- Step 04 – the assessment of the installed technical, mechanical, heating-cooling systems and their layout, aiming at planning how new devices can be implemented or integrated in order to reach a higher level of performance;

- Step 05 – the design of the technological solution to be adopted and its assessment through the calculation of the material embodied energy, related to the expected environmental effects of its application during the planned lifespan.

The addition models and the general design approach criteria, as defined in the first stage of the research, were tested in some application cases, in order to study the correlation between the different solutions and their effects on the performance level of the building [8].

Fig. 1 *Refurbishment strategies abacus of the investigated building block case studies*

3 Case studies investigation

Among the investigated case studies, two main typologies were considered: the typical housing block and the terraced houses so widespread in several Italian and European cities.

3.1 Refurbishment strategies on housing block

As shown in figure 1, several refurbishment strategies for social housing blocks were investigated in order to assess the effects of transformation process and different technical solutions.

Moreover, a useful base for testing the procedure was provided by the retrofitting of a residential block [9] built in 1975–76, owned by ACER Forlì and located in the suburbs, close to the city centre. The tall multi-storey building contains 36 apartments of 6 different dimensions, ranging from 45 m^2 to 92 m^2 of floor area. The prefabricated wall panels have a internal reinforced concrete structural layer, an external brick skin, and a thermal insulation layer between them (EPS insulating panel, 5 cm thickness).

The diagnostic phase highlighted several lacks in functional performance and residential space layout. The most relevant are: an inadequate range of apartment types and dimensions with regards to user profiles; the barriers affecting disable people accessibility, and a high energy consumption level for building heating (EP_{tot} = 153,37 kWh/m² year), mostly due to the poor thermal insulation of the envelope and the inefficiency of the existing heating systems.

The recovery of the deficiencies registered by the diagnostic phase was adopted as target for the design of the building refurbishment since the beginning, [10], focusing on three different solutions at increasing levels of transformation, by comparing their effects.

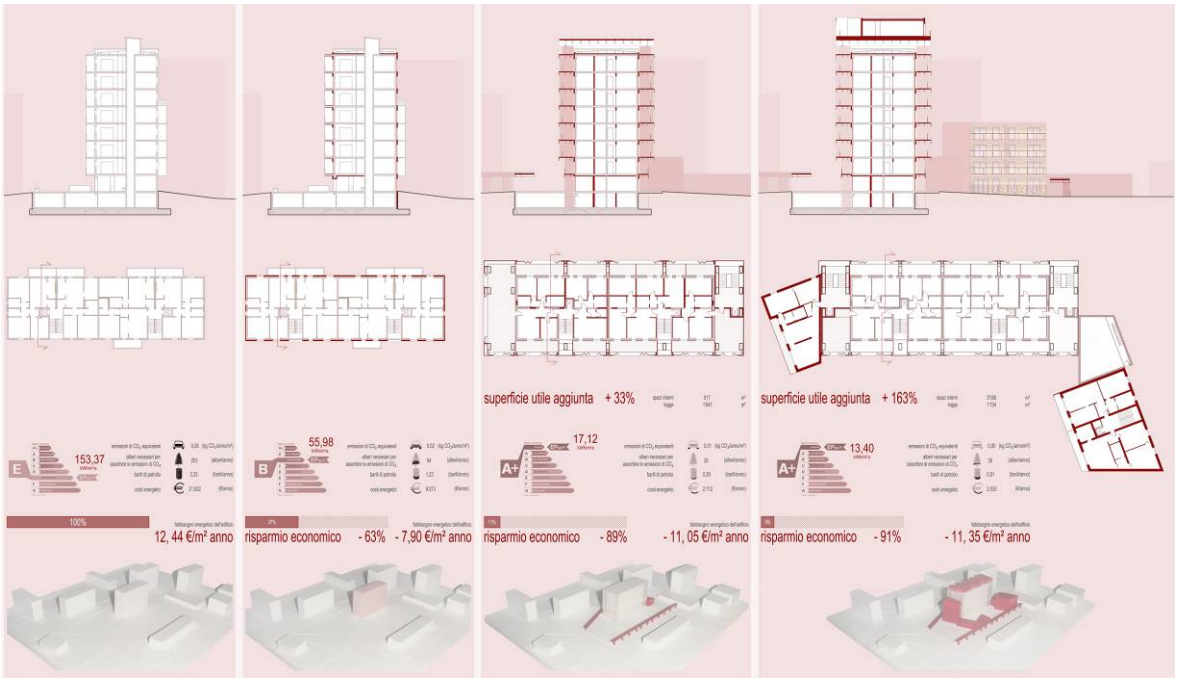

Fig. 2 *Levels of intervention and performance obtained.*

3.1.1 Levels of intervention

For the first level of transformation, called 'energy retrofitting', the improvement of the envelope thermal insulation up to the minimum level required by law was the only measure proposed: the replacement of the windows and the application of an external insulation layer on walls and roof allowed a reduction in energy demand of 56 kWh/m² year.

The second level of intervention consisted in the application, on the four façades, of a 'multifunctional envelope" capable of extending the flat size and of increasing the number of flat typology. The added envelope hosted new and more performing technical installations for heating and ventilation and useful vertical connections. Once verified the existing building structural performances, an independent metal frame with steel reticular pillars and laminated beams was proposed to be added to the façade. It was designed to carry a volumetric addition on top of the building. This second solution increased the usable floor area by 33 % and reduced the consumption level to about 17 kWh/m^2 year.

A third level of transformation was outlined by designing a further densification of the plot: two new 'volumetric additions' were located close to the two smaller sides of the existing building. They increased the usable area by 163 % and reduced the energy consumption by 91 % in respect to the original situation, with significant improvement of

the comfort levels too, thanks to the screening systems, the greenhouses and lodges, combined with the substantial effect of the envelope better performances.

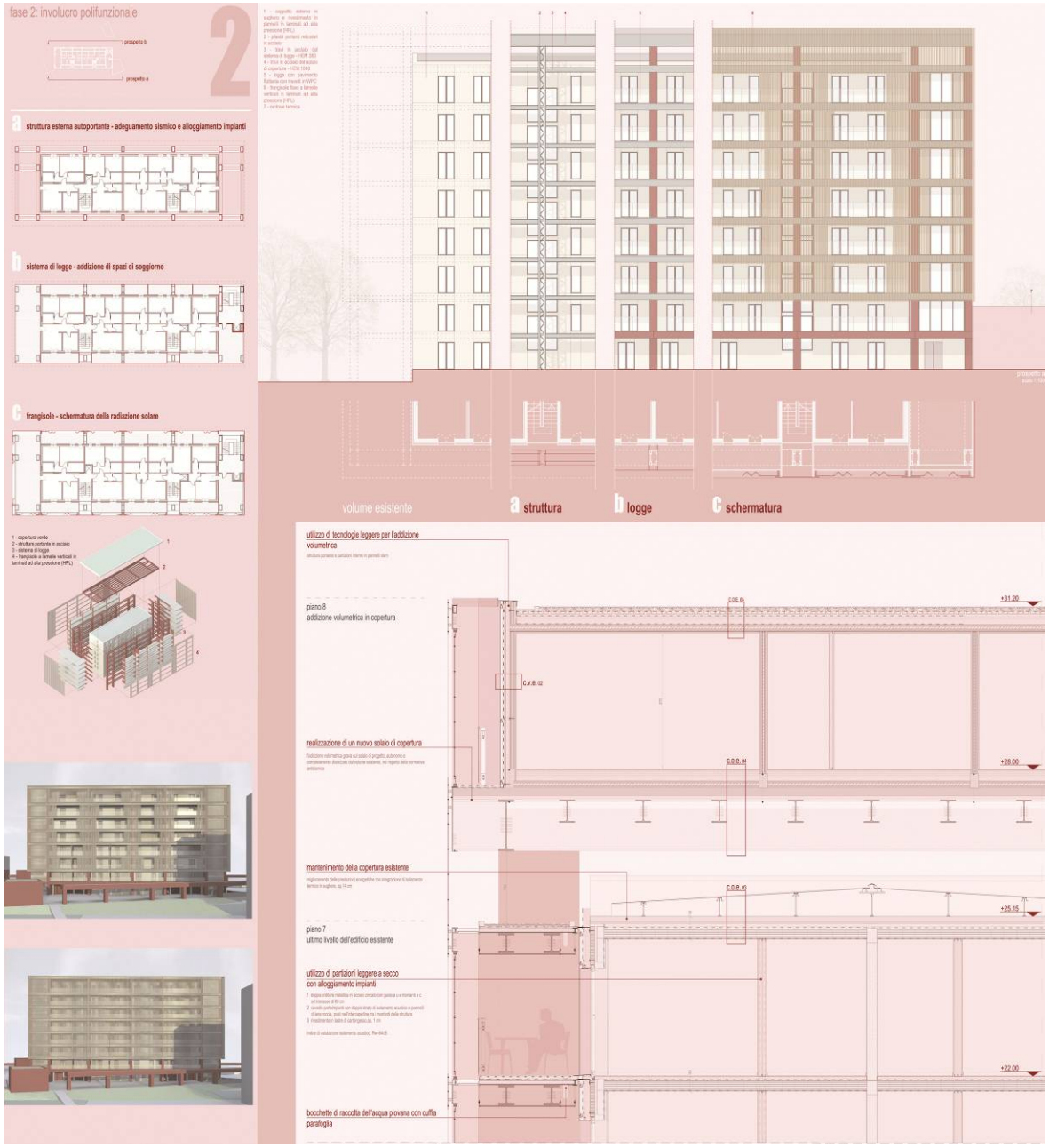

Fig. 3 *Synthesis of the technological solution adopted for realizing the volumetric additions.*

3.2 Refurbishment strategies on terraced housing

The case study selected for the terraced housing typology – Bel Poggio Neighbourhood – was built in 1973 and is located in San Lazzaro, a district close to Bologna. So, both the location and the construction period are similar to the previously considered case study. The building combines the general features of the row typology with some specific characteristics such as the distribution on four levels, brick fronts and an east-west orientation. The energy assessment gave the unit an overall performance index of more

than 206 kWh/m^2 per year, which is quite higher than the average value for the Italian existing building stock. The needs for winter heating reached 183 kWh/m^{2}y, and for hot water 23 kWh/m^{2}y. Energy loss mainly affected the two east and west sides (about 30 % of the total), the flat roof (12 %) and the basement floor (13 %). Two different intervention strategies were explored [11].

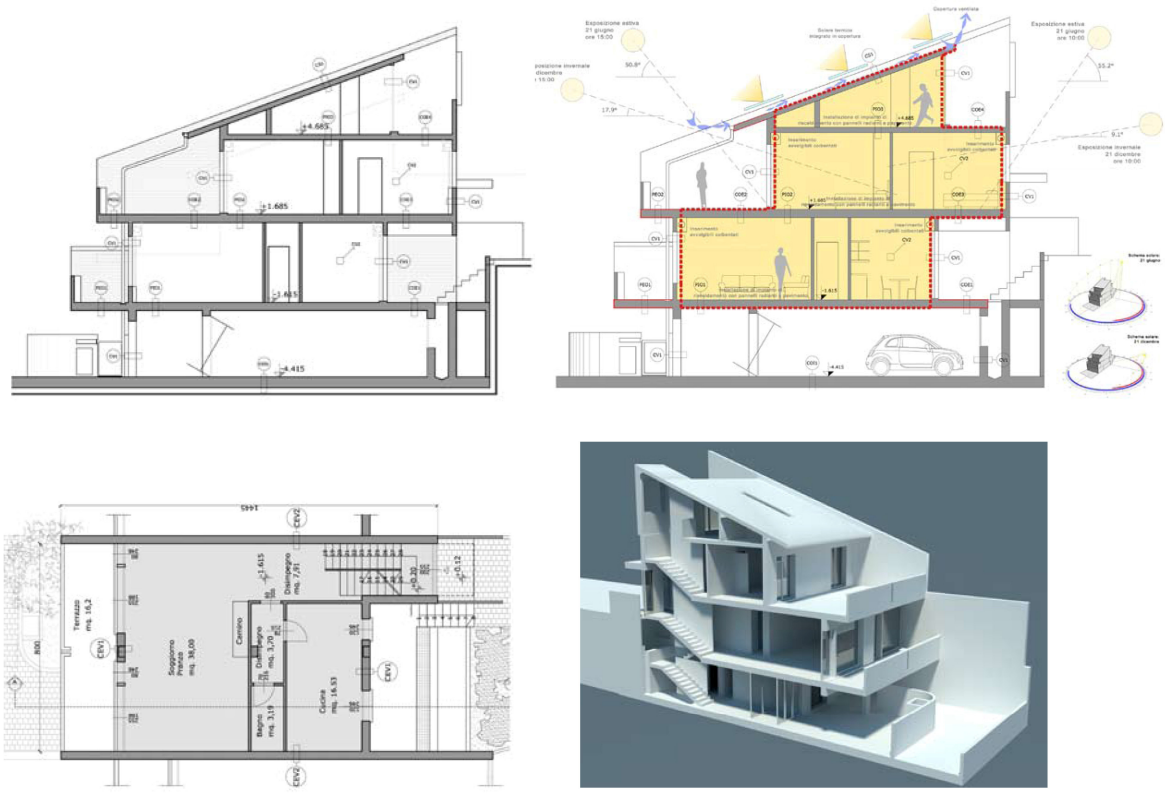

Fig. 4 *Typical plan and cross section compared to the one with the added insulation layer.*

3.2.1 Implementation of the building envelope

The first strategy adopted focused on preserving the image of the existing building and improving the performance of the building envelope by adding a new insulation layer from inside. This intervention, less effective and technically more complex than the insulation from outside, foresees the use of dry technologies and innovative materials. The insulation layer was calculated using a simulation model strictly corresponding to the shape and geometry of the external closures.

The use of partially prefabricated lightweight components could speed up the construction phases, and achieve a higher and more controlled technical level. All the technical choices were addressed to maximize energy efficiency, but – at the same time – were thought suitable to be applied to most part of this recurring typology with affordable costs. Double glazing glass windows (Uw = 1.3 W/m^{2}K) were preferred to high performing triple glazing ones due to the costs and to the average performance of the building envelope. After intervention the energy assessment gave the unit an overall performance index of 50.68 kWh/m^{2}y, reducing the total energy demand to less than a quarter (24, 60 %) of the starting conditions.

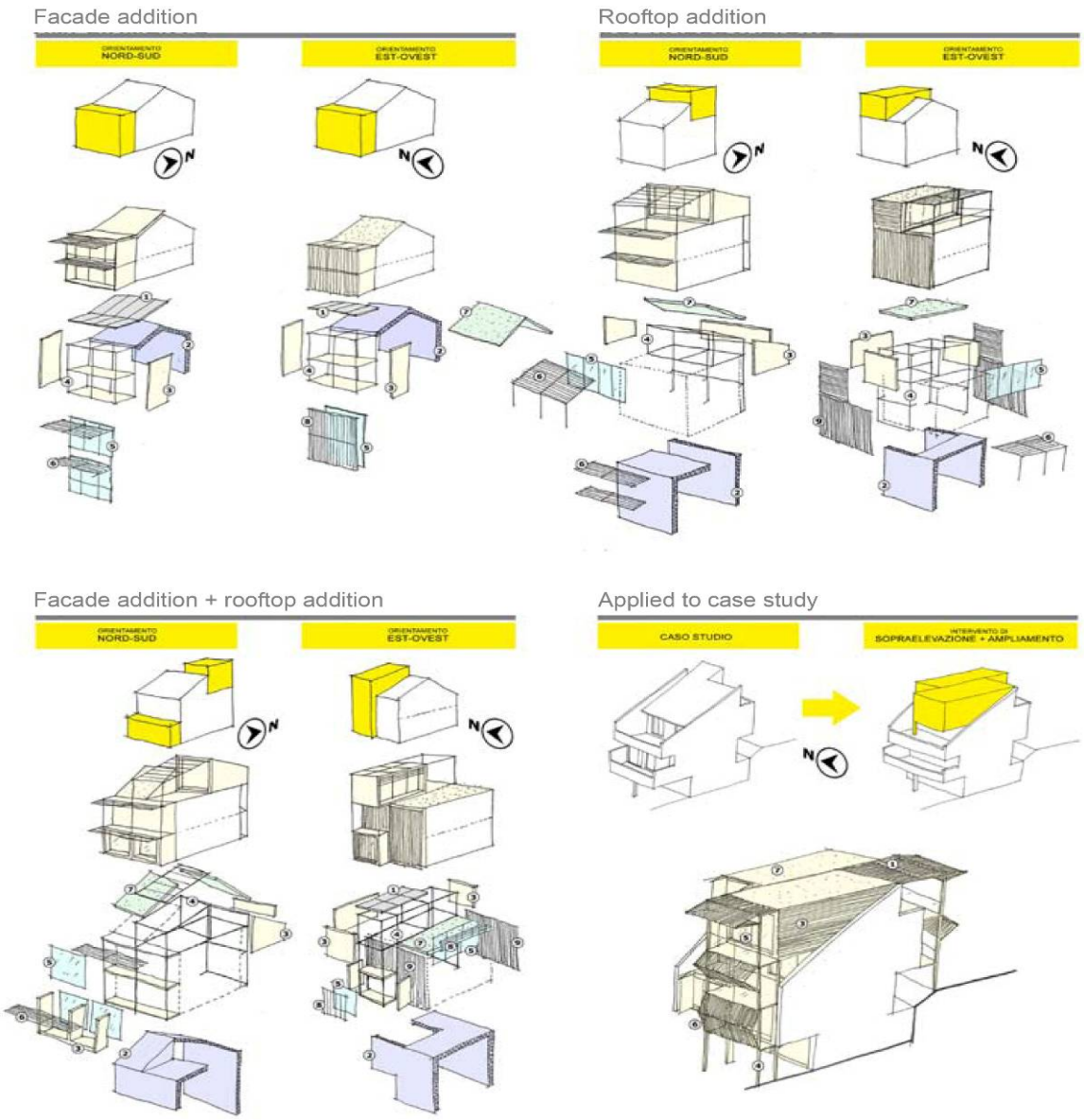

Fig. 5 *Sketches concerning the development of the volumetric addition in a row housing unit.*

3.2.2 Volumetric additions

The second intervention strategy investigated the possibility of adding volumes on both the façade and the roof. Some balconies and volumes were placed on the fronts and on the roof of each units, so that the units floor area could be increased by 20 to 35 %, contributing to the energy efficiency of the whole building and improving passive benefits derived from passive and active solar gains (solar collectors and photovoltaic systems can be integrated on the roof and on the new volumes). Natural ventilation and shading systems were provided in order to improve the building envelope behavior during summer. The final layout allowed a very flexible solution and included in each unit an independent additional small flat, suitable for extended families (elderly relatives, children). The energy assessment of the combined existing and added volumes gave an overall energy performance index of 43.37 kWh/m^{2}y, reducing the energy demand by one-fifth (21 %) when compared to the initial conditions. The additions were provided by using dry technologies in order to

facilitate the compatibility with the existing structures, speed up the transformation phase, allow reversibility, and obtain a high level of performance and efficiency at low costs.

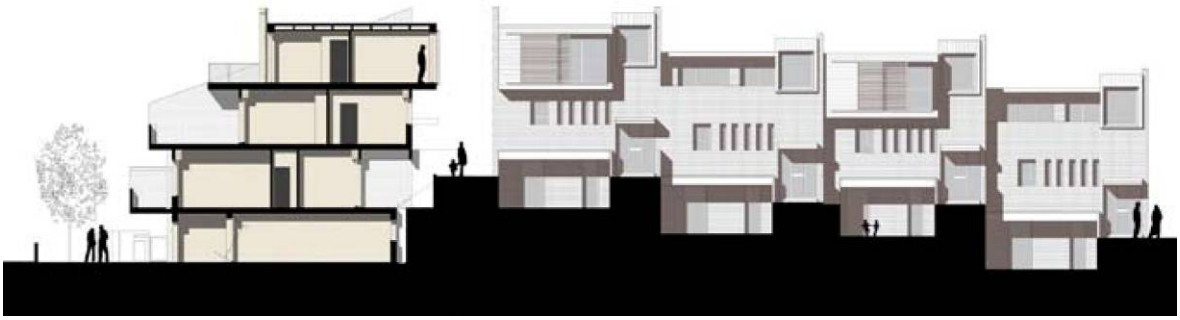

Fig. 6 *Cross section of the refurbished unit and study – elevation considering the overall transformation of the row housing façade.*

According to the refurbishment intervention on each unit a simulation was performed in order to evaluate the impact of the volumetric additions on the overall elevation of the housing, taking into consideration different solutions and different density of added volumes. The characteristics of reproducibility were also investigated in a more general framework.

4 Conclusions and final remarks

After several case studies were considered and a number of technological solutions for refurbishment were investigated during the first stage of the research activity some key issues can be pointed out:

- Increasing the functional and technical performances of existing buildings by adding new volumes is a design strategy that can combine architectural quality and energy savings as integrated goals to reach.
- Additions allow to provide new spaces, new services and new devices capable of improving the quality of both the single unit and the entire building as a whole.
- The increase in quality can also improve the relationship between the building and its urban surroundings, encouraging the adoption of densification policies capable of improving the functional and social mix of the neighbourhood.

So the way the additions are laid out is a strategic design issue. The methodology adopted is aimed at allowing the planned refurbishment actions by reducing the use of primary resources and by maximizing the useful life of components. The results obtained in the case studies are summarized in table 1.

Tab. 1 *Synthesis of the benefit produced by the addition strategy.*

	housing block	**terraced housing**
Floor area increasing	33%	35%
Energy demand reduction	-89%	-79%
Starting Ep	153,12 kWh/m^{2}y	206 kWh/m^{2}y
Final Ep	17,12 kWh/m^{2}y	43,37 kWh/m^{2}y

Some new criteria should be introduced during the design phases. The idea of designing a building that can be transformed through time stems from the use of technological

solutions that can be removed, as dry and assembled constructions, but also especially from a different view of the relationship between the building different elements and sub-systems. Furthermore, a balanced approach between the energy savings deriving from the refurbishment actions and energy investments needed to achieve the renewal is a key factor in considering from the right perspective the role of intervention in extending the life cycle of the building. In order to prevent speculations and promote an improvement of quality in refurbishment actions, suitable guidelines on how to approach the design phases are necessary.

References

[1] DI GIULIO, R., (edited by) *Improving the quality of suburban building stock*, Faculty for the built environment, University of Malta, Malta, 2010.

[2] GOULDING, J. R., LEWIS, O., *Sustainable & energy efficient building*, James & James, London, 2001.

[3] FORSTER, S., "Nachhaltiger Stadtumbau", in *Umrisse* 1, 2001.

[4] JØRGENSEN, O. B., "Flexren, flexible façade system for energy conscious renovation of European houses", in AA. VV., *Northsun 2001 Technology meets market in the solar age*, Conference proceedings, Leiden, 2001.

[5] BOERI, A., LONGO D., "High density suburbs redevelopment and social housing retrofitting for cities regeneration" in BREBBIA, C.A., PACETTI, M., PASSERINI, G., LATINI, G., *Sustainable City VII – Urban Regeneration and Sustainability*, Southampton, WIT Press, 2012, pp. 133–144.

[6] ANTONINI, E., GASPARI, J., OLIVIERI, G., "Densifying to Upgrading: strategies to improve the social housing built stock in Italy" in *TECHNE*. vol. 4, 2012, pp. 306–314.

[7] GASPARI, J., "Architectural and technological additions as strategies to improve urban quality in refurbishment actions" in DI GIULIO, R., (edited by) *Improving the quality of suburban building stock. Improving the quality of suburban building stock* – COST ACTION TU0701 international final conference. Ferrara, Unifepress, 2012, vol. 1, pp. 413–419.

[8] DRUOT, F., LACATON, A., VASSAL, J., *plus*, Editorial Gustavo Gili, Barcelona, Spain, 2007.

[9] CALBUCCI, L., VENZI, E., *Ri-abitare il margine urbano. Strategie di riqualificazione per il social housing: un edificio residenziale "ACER" come modello d'intervento*; Graduation Thesis in Architecture, University of Bologna, Supevisor Prof. Andrea Boeri, 2010.

[10] FORSTER, S., "Radical conversion instead of demolition – from prefabricated panel construction to garden city", *Detail* 7/2000.

[11] BOERI, A., ANTONINI, E., "Riqualificazione energetica e rifunzionalizzazione della tipologia a schiera" in Paesaggio Urbano. vol. 4, 2010, pp. XX–XXVII.