Proceedings Paper:

Iuorio, O and Romano, E (2017) Energy retrofit approach towards a multi-performance renovation of existing buildings. In: Proceedings of the International SEEDS Conference 2017. International SEEDS Conference 2017 (Sustainable, Ecological, Engineering and Design for Society), 13-14 Sep 2017, Leeds, UK. Leeds Beckett University .

SEEDS International Conference

Energy retrofit approach towards a multi-performance renovation of existing buildings

Ornella Iuorio[1], Elvira Romano[2]

[1] University of Leeds, School of Civil Engineering, Leeds, LS2 9JT, United Kingdom

[2] University of Leeds, School of Civil Engineering, Leeds, LS2 9JT, United Kingdom

Keywords: Building Sustainability, Envelope Retrofit and Integrated Renovation.

Abstract

The increasing concerns over population growth, depletion of natural resources and global warming as well as catastrophic natural events is leading the international scientific community to envisage sustainability as a crucial goal. The built environment plays a key role on the triple bottom line of the sustainable development - Planet, People, Profit - because of several environmental, social and economic impacts produced by the construction sector. The acknowledged need to promote a sustainable building market is an international high-priority issue as underlined by the 2030 Agenda for Sustainable Development. Indeed one of its strategic objectives highlights to make cities and human settlement inclusive, safe, resilient and sustainable. In line with the 2020 Europe Strategy and the European 2050 Roadmap, energy efficiency and CO_2 savings towards a low-carbon economy are regarded as ambitious objectives to be achieved for both new and existing buildings. Thus energy retrofit becomes a fundamental and growing research area to be investigated.

This study aims to investigate the opportunity to develop sustainable integrated renovations that can improve energy and structural performance and at the same time provide economic and social benefits. A brief overview on the main characteristics and criticalities of the EU existing residential building stock is introduced. The work emphasizes the possibility to use envelope retrofit practice based on prefabricated modules as a potential measure to optimize the energy performance and increase occupants' comfort and economic property value. The benefits of the investigated solutions are evaluated according to a multi-performance life-cycle oriented approach. Finally, a discussion on the possibility to apply the proposed methodology to residential high rise buildings in Leeds is exposed.

INTRODUCTION

Nowadays, the significant increase of urban areas has led the building and construction sector to explosively grow into one of the largest global industries with immense consequences for all three dimensions of Sustainable Development - Environment, Economy and Society. In line with the most accredited definition of sustainability, as firstly stated by the 1987 Brundtland report, it is essential to meet needs (Brundtland, 1987) of a world population, which has more than doubled since 1950. According to United Nations (2016), around 55% of the world's seven billion inhabitants lived in cities and urban areas in 2016: a trend which is expected to increase to 66% by 2050, making the planet for two-third urban. A direct effect of this rapid urbanization process is the growing exposure to a higher risk of mortality and/or economic losses for an increasing number of cities' dwellers located in natural disasters vulnerable areas. Consequently, an urgent action to promote sustainable and smart cities is highly recommended at international level. The worldwide scientific community is seriously involved assuming drastic measures to mitigate and adapt against the effects of climate change and the degradation of natural defenses, as indicated by the first *Intergovernmental Panel on Climate Change* (IPCC) report (1990), the *Kyoto Protocol* (1997) and the *Paris UN Climate Change Conference* (COP21) (2015). This latter international plan has marked an historic turning point in global action on climate change, establishing for the first time a legally binding and climate agreement which sets the world on a zero carbon, resilient and fair future.

At the European level, the construction sector is at the hearth of the *2020 Europe Strategy*. Buildings are responsible for 40% of total EU energy consumption, 36% of GHG emissions and a third of the total European waste (EU, 2012). Moreover, the construction sector generates 10% of GPD on European economy and people spend 90% of their time inside buildings, so comfort, safety and healthy indoor environment have to be guaranteed. Thus, over the last two decades European Commission has been boosting the promotion of sustainable constructions, launching several initiatives and action plans as a first step towards the eco-efficiency objectives. In addition the perspectives to a low carbon economy make this sector one of the most suitable for meeting the ambitious EU goals of reducing CO_2 emissions by at least 80% and energy consumption by as much as 50% by 2050. In such a way, the energy requirements for achieving the so-called '20-20-20' targets by 2020 are strengthened. These theoretical concepts have been implemented through policy mechanisms and codification, leading the EU legislative context to adopt regulatory instruments with specific binding characteristics, such as the 2010 recast of *Energy Performance of Buildings Directive (EPBD)* and the 2012 *Energy Efficiency Directive (EED)*, the EU's main legislation covering the reduction of the energy consumption of buildings. The former addresses the operational energy use of buildings and its review particularly highlights the achievement of nearly Zero Energy Buildings (nZEBs) for all new and undergoing major renovation constructions by 2018 and 2020 for the public and private sector, respectively. The EED sets out energy savings requirements for EU countries' buildings which include the request to establish national plans for renovating overall building stock, since older and more obsolete buildings are associated to the largest energy saving potential (BPIE, 2011). The EU existing building stock, considering both the residential and the non-residential sector, accounts for 25 billion m^2 of useful floor space in the EU27 (BPIE, 2011). The residential building stock is the biggest segment with a floor space of 75% of the total buildings and it is estimated that 64% of the residential building floor area is associated with single family houses (SFH) and 36% with apartment blocks. More than 40% of residential buildings have been constructed before the 1960s, followed by a large percentage built among 1961-1990 when the housing stock almost doubled (BPIE, 2011). It is worth analysing some important factors in the refurbishment process. Renovation measures are certainly affected by location, in terms of energy demand, structural typology and scale. Indeed, economies of scale can come into play with large-scale renovation programs, enabling actions on streets and districts. Although big emphasis is posed at the European level on energy efficiency, focusing on the built environment, often buildings requiring energy retrofit also need structural improvements. Indeed, it is clear that these buildings have exhausted their design service life and the possibility of their further usage should be determined based on the result of a thorough structural assessment analysis (Marini *et al.*, 2014). Thus, structural retrofit interventions should be absolutely taken into account together with energy retrofit.

The present contribution aims to highlight the importance of considering an integrated multi-performance based approach for building retrofit that accounts for all the aspects of the sustainable development. In the next sections, a discussion on possible energy retrofit approach is carried out. Emphasis is posed on the possibility to consider envelope retrofit practice as a mean to exploit the integration of energy efficiency with the improvement of environmental, social and economic issues. A brief overview on conventional and innovative energy retrofit measures is exposed, focusing on potential prefabricated systems solutions. Then a multi-performance life-cycle oriented methodology for an integrated retrofit of existing buildings is presented. The potential application of this approach to residential high-rise buildings in Leeds (UK) is briefly presented.

ENERGY RETROFIT APPROACH FOR EU EXISTING BUILDINGS

The building sector is one of the key consumers of energy in Europe. Buildings demand energy during their whole life-cycle both directly (for construction, operation and eventually demolition) and indirectly (for possible mining, processing and production of construction materials) (Sartori and Hestnes, 2007). The **utilisation phase** of a building is the longest stage of its life-cycle, usually lasting many decades and accounting for the greatest part of building's energy use which is demanded for living environment heating, heating of drinking water, lighting, ventilation cooling and air conditioning systems. Focusing on the residential sector, in 2009 EU households were responsible for 68% of the total final energy use in buildings. In particular, heating consumes the largest amount of energy in households, accounting for 65% in 2010 in EU-27, followed by water heating and appliances/lighting. In relation to space heating unit consumption per dwelling (Online: Entranze tool) (Fig.1 a), it is worth noting that in Southern countries, such as Portugal and Italy the energy use is relatively high despite heating needs are lower due to milder winters, which provide an indication of insufficient envelope thermal insulation in their building stocks. Moreover, a wide variation in energy and electricity consumption per dwelling (Online: Entranze tool) for different European countries in 2010 can be observed (Fig. 1b and 1c) with a higher consumption in Northern and Western Europe than in Southern and Eastern Europe, substantially. These geographical differences are important to keep in mind when designing measures to increase energy efficiency.

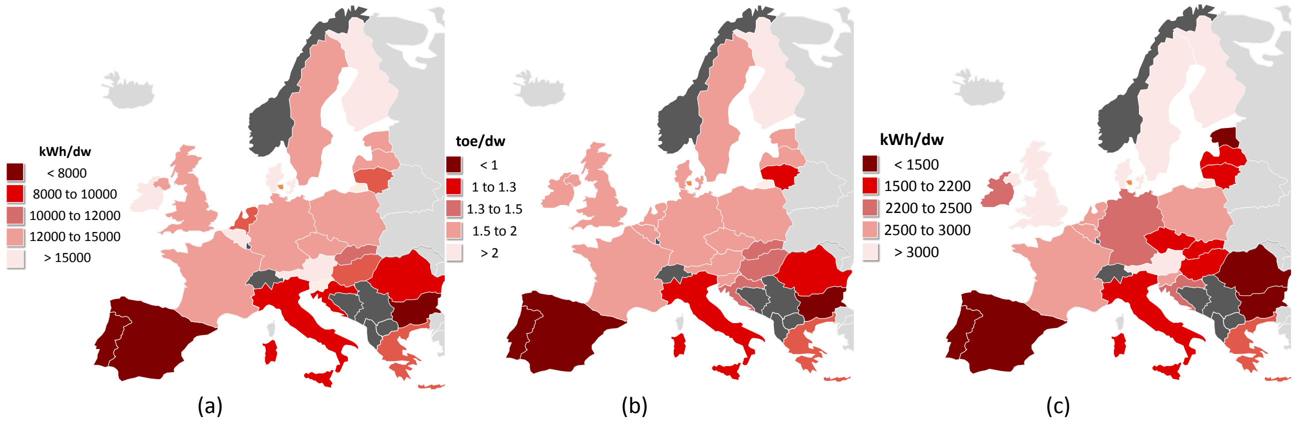


Figure 1. EU consumption of (a) space heating unit; (b) energy and (c) electricity - lighting, electric appliances (Data source: Entranze tool)

The energy performance of households depends on various factors such as the performance of the installed heating system and building envelope, climatic conditions, behavioural characteristics and social circumstances. Energy renovation of the EU building stock turns out to be not only the key to reach the climate targets, but it can also be seen as a vehicle to improve economic and social conditions. Building energy retrofit measures can be categorized in four main groups on the basis of the element on which the improvement intervention is made: (1) building facade (i.e. walls and windows); (2) overall building envelope; (3) energy systems (i.e. HVAC, lighting etc.) and (4) installation of renewable technologies (BPIE, 2011). According to 2011 BPIE report, building renovation can be classified in four different types (Table 1), depending on the number of the adopted energy retrofit measures and on the consequent levels of associated energy saving.

Renovation type	Improvement measure	Final energy saving (% reduction)	Indicative saving (modelling)	Average total project cost (€/m^2)
Minor	Single as new boiler plant or insulation	0 - 30%	15%	60
Moderate	3- 5 interventions	30 - 60%	45%	140
Deep	Holistic approach	60 - 90%	75%	330
nearly Zero Energy Building (nZEB)	All energy retrofit measures	+ 90%	95%	580

Table 1, Renovation type and economic investment estimates (Source: BPIE, 2011).

Nevertheless, emphasizing exclusively the optimization of energy efficiency is ineffective. This approach does not meet overall sustainable requirements of the actual international and European strategies. The built environment is a key element in determining quality of life and contributes to cultural identity and heritage. Thus, according to McKinley (2012, p. 13), '*a sector focused solely on financial and economic performance without capitalizing on value creation from social and environmental innovation, is a business dead-end*'. In that line, the energy improvement based on an envelope retrofit approach becomes an interesting opportunity to improve the entire building fabric thanks to an integrated renovation, acting in a way that is not simpler and faster but smarter. It is acknowledged that interventions on mechanical and electrical systems maximize energy reduction for minimal investment. Nevertheless an energy retrofit approach that focuses solely on equipment upgrades is '*effective but limited in the overall energy savings it can generate*' (Griffin, 2016, p. 7). In historical buildings, services are upgraded on a cyclic basis, whereas alteration of the building fabric can be very restricted. Nevertheless, when such an intervention is possible, it can persist for an important portion of the life cycle of the building fabric. Therefore, in a logic of carbon reduction, any improvement of the thermal performance of the building envelope should be prioritized (Iuorio, Barbalace and Fernandez, 2016). The envelope is recognized as the most critical part in relation to energy efficient buildings, considering that it impacts 57% of the building thermal loads (EU, 2012). For this reason energy efficient building should use envelopes that are durable, adaptable and cost-efficient. According to Kamel and Memari (2016), energy envelope retrofit approach could be simply categorized into *conventional* and *deep* energy retrofit using different measures in order to improve energy performance. Simple and fast methods are used in the former case, while a whole-building retrofit approach is considered for the latter one. An overview of the current conventional and innovative energy retrofit measures of the building envelope is therefore presented in the following paragraph.

Conventional and innovative envelope retrofit measures

The easiest measure to enhance the energy performance of buildings is to improve the thermal performance of the building envelope through the insulation of walls, floors and roofs and the replacement and tightening of windows and doors. With regard to **external walls and roofs,** two main ways of obtaining improved thermal insulation need to be considered: (1) Increasing the thickness of the insulation, even if various disadvantages such as the cost of construction and the loss of space could occur and (2) Improving the thermal insulation properties by reducing the thermal conductivity of the insulation material.

In the last years the development of new technologies for the energy performance improvement has been greatly investigated. In that line some outstanding techniques for the envelope retrofit aimed at reaching a high energy performance can be mentioned. Within the insulation solutions, some innovative materials have been developed such as the Vacuum Insulation Panels (VIPs): flat elements consisting of an open porous core material which has to withstand the external load caused by atmospheric pressure, as well as a sufficiently gas-tight envelope to maintain the required quality of the vacuum. VIPs, compared to conventional insulation materials of the same thickness, save about 26 kWh per m² component area and about 7.3 kWh per m² useful building floor area (EU - JRC, 2012). Other effective techniques regard roofs. In particular, a **cool roof** is a system able to reduce cooling demand and to reflect solar radiation, providing several benefits such as reduced air conditioning use, resulting in 10% - 30% energy savings; decreased roof maintenance due to its longer life and increased occupant comfort. A **Green roof**, instead, acts as an insulation layer and it can be categorized in extensive and intensive, having a thin layer of growing material and a greater soil depth, respectively. These systems reduce heating demand and provide benefits going beyond the thermal balance such as enabling biodiversity, reducing urban heat island effects and water run-off. An innovative system related to façade retrofit is the **Active Solar Thermal Façade (ASTF)** which functions as both a building envelope and a solar collector component and it can be used as part of walls, windows, balcony, sunshield and/or roof (Zhang *et al.*, 2015). Another innovative energy retrofit solution is the **Double-Skin Façade (DSF)**, based on the notion of exterior walls that respond dynamically to varying ambient conditions. In addition, they can incorporate a range of integrated sun-shading, natural ventilation, and thermal insulation devices or strategies. Further details could be found in (Musa and Alibaba, 2016).

Prefabricated modular systems for envelope retrofit

Building renovations with the integration of prefabricated façades and roof elements can provide an opportunity to improve the architecture and quality of the existing building envelope, while ensuring energy saving. In particular, prefabricated renovation modules demonstrate that industrialized prefabrication technologies are no longer only the domain of new buildings (IEA - ECBCS, 2011). They have a large potential for building renovation where they offer a better quality of workmanship and a faster construction process. The use of prefabricated modular systems present several sustainable advantages such as optimized constructions quality and flexible systems, cost efficiency due to prefabrication, a quick renewal process with minimized disturbances for the inhabitants, a dry construction process, an easy maintenance for planned and/or repair interventions and the potential reuse of elements at the end of the life-cycle. Several European renovation programs demonstrate that validated envelope prototypes could be the starting point for holistic retrofit strategies leading to urban renovation projects. Indeed, in order to categorize the interventions it could be possible to classify the retrofit approaches on a three scale basis:

1. At the scale of the **element**, when the retrofit invests only walls and/or floors and roofs (Fig.2);
2. At the scale of **building**, when the whole building is retrofitted with new technical and architectural additions which can also inform a new internal space distribution (Fig.3);
3. At the scale of the **neighborhood**, when a system of buildings and eventually the common external areas are retrofitted following a common approach that will deliver not only energy improvements, but also an overall urban regeneration (Fig.4).

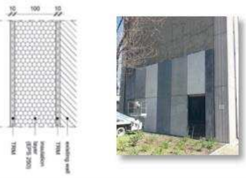
Envelope element	Key technologies	Energy Retrofit benefits	Sustainable benefits
1. Solid exterior wall 	• Innovative prefabricated panel made of Textile Reinforced Mortar (TRM) with a core made of Polystyrene foam • HPFRC anchoring system	Decrease in heat loss: **65%**	**Environment** • Energy savings • CO_2 reduced emissions • Increased indoor comfort
2. Cavity wall 	Advanced hydrophobation process for: • Natural Expanded Perlite (NEP) • Synthetic Expanded Perlite (ESP).	Decrease in heat loss: **85%**	**Society** • New jobs generation • Regeneration of urban areas • Safety in installation
3. Interior wall 	Three different kits: • perlite board • aerogel wallpaper • flat laminated aerogel board	Decrease in heat loss: **25% - 45%**	**Economy** • Financial savings • Accessible payback periods

Figure 2. Example of retrofit approach at the 'element' scale (Data source: EU - Cordis, 2012, pp.9-21)

Renovation Project	Key technologies	Energy Retrofit benefits	Sustainable benefits
Residential area - Dieselweg 4 / Graz, Austria			
Before (1970) **After (2008)**  • Energy inefficiency • No insulation in exterior walls, ceiling and floors • Poor thermal comfort and living quality	 • Solar façade with **solar comb**, arranged on the **OSB board** and covered by a **glass panel**	Heating Energy Reduction: **93%**	• Potential to achieve energy efficiency • Adapt the building for future needs • Cover most of the cost in the entire lifecycle

Figure 3. Example of retrofit approach at the 'building' scale (Data source: IEA - ECBCS, 2011, pp.49-56)

Renovation Project	Key technologies	Energy retrofit benefits	Sustainable benefits
Edward Woods Estate (West London/UK Rockwool)			
Before **After**  Three 1960 residential tower blocks: • Poor thermal comfort • Fuel poverty for occupants	• High grade external • Wall insulation • Cavity wall insulation • Roof insulation • Coloured façades • Integrated photovoltaic solar panels • New penthouse flats	U-value achieved: **0.29 W/m²K**	• Improve communication with residents, explaining the work purpose and the potential benefits • Help residents understand the importance of changing wasteful energy behaviour • Relocating vulnerable residents

Figure 4. Example of retrofit approach at the 'neighbourhood' scale

In summary, depending on the building location, the existing envelope systems and the climate zone, the envelope retrofit based on prefabricated modules might be focused on different components at different scale levels, becoming a potential measure to optimize the energy performance and increase occupants' comfort and economic property value in the perspective of a sustainable integrated urban renovation.

A SUSTAINABLE INTEGRATED RETROFIT (SIR) METHODOLOGY

The Rio +20 Conference outcome - *The future we want* - recognized that cities can lead the way towards economically, socially and environmentally sustainable societies, but a holistic approach to urban planning and management is needed in order to improve living standards of urban and rural dwellers (UN, 2014). This argument perfectly fits in the renovation of the existing residential buildings which are integral part of the urban areas and represent the majority of EU building stock. Besides the acknowledged poor energy performance, the majority of existing properties show a lacking planned maintenance and an inadequate interaction with the urban and social context, as well as structural deficiencies (Marini *et al.*, 2014). Best practice for existing buildings retrofit are needed. In order to fulfil the increasing EU request of energy improvements for the residential sector, an envelope retrofit based on prefabricated modules could be the most effective solution to ensure not only energy savings and CO_2 emission reduction, but also to satisfy several Planet, People and Profit requirements. In addition, structural improvements need to be ensured as well, stimulating an integrated renovation. In order to properly address this issue a Sustainable Integrated Retrofit (SIR) methodology is needed, as discussed in the next paragraph.

An integrated approach for sustainable retrofit: basic principles and main steps.

In the last years particular attention of the civil engineering research has been devoted to the sustainable structural design of new buildings. Similar approach can be applied to sustainable retrofit interventions on existing buildings (Romano *et al.*, 2015).
In line with the traditional approach, structural design is mainly focused on the construction phase and the first use stage. According to Sarja (2003, p. 1002), '*maintenance and repair are reactive'.* Their need is not considered in the design stage, and during use they are mostly realized at a very advanced stage of deterioration, causing huge investments in repair measures, or even the need of demolition. In such a way burdens on the economy, the environment and the society are produced. In that line, **design for the life-cycle** becomes the possible answer to conceive sustainable retrofit solutions for existing buildings. It means to make decisions related to structural, environmental and economic requirements in the design phase of a retrofit intervention that will affect the entire life-cycle, becoming a tool to ensure an adequate degree of reliability, reduce costs, increase occupants' comfort and protect the Planet. On the basis of the main principles of the sustainable structural design, the sustainable retrofit is an integrated time-dependant multi-performance based design and/or assessment methodology, which takes into account the performances of a building related to the environment, the economy and the society during the whole life-cycle, without neglecting the structural performance. This methodological design philosophy is aimed at maximizing mechanical, durability, economic, social and environmental performance of a structure during the whole life-cycle, reducing at the same time the negative impacts played on the three dimensions of sustainability (Landolfo, Cascini and Portioli, 2011).
In line with the sustainable structural design approach (Landolfo, Cascini and Portioli, 2011; Romano *et al.*, 2015), three key points characterize the **Sustainable Integrated Retrofit (SIR)** (Fig. 5a):

1. It is a **multi-performance** based design approach, focused on the extension of the number of requirements to be satisfied. New sustainable needs such as reduced environmental impacts,

optimized life-cycle costs, optimized building management need to be considered together with traditional requirements of reliability, safety and serviceability.

2. It is a **life-cycle** oriented methodology: the considered time unit goes beyond the ordinary design working life and it may include all the stages of the construction's life according to the cradle-to-grave approach.
3. It envisages the use of **quantitative procedures** for the design of retrofit interventions, based on performance levels in accordance with the assessment methodologies developed in the framework of international research and received by ISO standards.

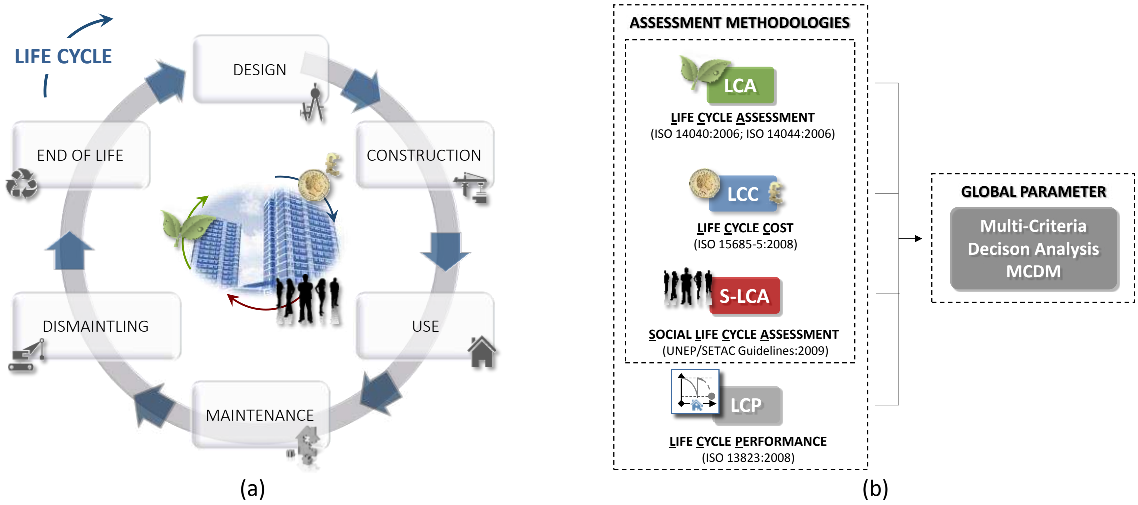


Figure 5. The Sustainable Integrated Retrofit (SIR) methodology: the approach (a) (Source: image adapted from Landolfo, Cascini and Portoli, 2011, p. 306) **and the main steps (b)**

It is worth noting that the main goal of the examined integrated approach is based on two essential aspects (Fig. 5b). Firstly, the quantitative sustainable performances assessment in a holistic way during the entire life-cycle of a building is required. Secondly, a method to integrate all the obtained results to achieve a global parameter is needed. In relation to the first step, the evaluation of the environmental performance is addressed by the **Life Cycle Assessment (LCA)** methodology in accordance with ISO 14040:2006 and ISO 14044:2006. The economic performance is assessed thanks to the **Life Cycle Costing (LCC)** methodology in the respect of ISO 15686-5:2008. LCC is an effective method to estimate costs in monetary terms arising during the life-cycle of a construction. LCC extends the cost analysis over the whole life of a building, going beyond the traditional approach which estimates only the initial costs for construction: maintenance, inspection and repair costs, as well as dismantlement ones are evaluated, showing the real value of the investment. The social performance is the less analyzed. Nevertheless important steps have been achieved thanks to the work of the *Life Cycle Initiative*, a joint organization UNEP/SETAC which defined guidelines for a **Social - Life Cycle Assessment (S-LCA)** methodology in 2009. Although a first generation of standards has been adopted thanks to both EN 15643-3:2012, focusing on the evaluation of social impacts of buildings at framework level and EN 16309:2014 dealing with the social performance assessment of buildings at use stage, other steps in this direction are needed. Finally according to **Life Cycle Performance (LCP)** assessment methodology in the respect of ISO 13823:2008, the structural performance could be assessed by a parameter measuring the reliability of a structure such as the failure probability in accordance with a specific limit state and/or a reliability indicator. Moreover, the verification of durability, considering service life scenario based on the prediction of the deterioration that will act on the structure leading to a decrease of performance can be assessed. According to a life cycle analysis, on the basis of ordinary maintenance operations and/or potential exceptional events during the use stage of the working life of the structure, it could be possible to define the period of time beyond that the structural performance are not ensured as required at the design stage. In relation to the second step, it is evident that the integration process could be complex because of the different performance measure units, therefore simplified methods need to be considered. These *integrated methods* are based on a **multi-criteria decision making (MCDM)** analysis. This technique consists of determining the optimal alternative among a set of solutions which are evaluated with respect to a set of criteria. In the context of sustainable assessment, the three dimensions of sustainability become the criteria. Then various sub-criteria can be defined for each criterion, expressing the objectives of the three dimensions. Once criteria and sub-criteria have been determined, it is possible to define the decision matrix, considering all the parameters involved in the decision process in a hierarchic scheme. The choice of a multi-criteria analysis in the integrated retrofit is a decisional task which may employ several methods. According to Ciutina *et al*. (2013, p. 111), '*the indicator-oriented methods are deficient due to ignorance of non-considered criteria'*. For this reason, other methods, such as the multi-axial representation or the characterization factor could be preferable towards the choice of the best retrofit solution.

An interesting approach to overcome the gap of the combination of different performances in a global result could be found in Romano, Negro and Taucer (2014). A **Sustainable Structural Design (SSD)** methodology is provided in order to include environmental aspects in structural design throughout the entire life-cycle of a structure, following three main steps: **(1)** Environmental performance assessment through the Life Cycle Assessment (LCA); **(2)** Structural performance assessment through the simplified Performance-Based Assessment (sPBA) and (**3)** Combination of environmental and structural results in economic terms. In such a way, all the requirements of a building are holistically balanced, obtaining a unique quantitative assessment parameter. On that basis this methodology could be suggested also for the design of retrofit interventions of existing buildings, even if it has been introduced as a methodology for the design of new structures. Nevertheless social aspects are completely excluded but they could be easily introduced thanks to the evaluation of the societal costs associated with domestic space heating and hot water energy efficiency. Further developments in this direction will be investigated in the future steps of research related to the Sustainable Integrated Retrofit methodology.

A DISCUSSION ABOUT THE POTENTIAL APPLICATION OF THE 'SIR' METHODOLOGY TO HIGH RISE BUILDINGS IN UK

In the UK, space heating consumes a large amount of energy. The 2013 UK Energy Statistics indicated that annually in domestic house sector 66% of toe was used for space heating and 17% for hot water production (DECC, 2014). Moreover, the heating cost accounts for around £33 billion each year. This large heating consumption level highlights the very poor energy performance of UK buildings, so energy retrofit is a high-priority issue for UK existing residential building stock. A significant portion of those properties is composed of high-rise buildings, based on industrialised systems such as the Large Panel System (LPS) constructions which were extensively built from the mid1950 to 1970. Currently, these buildings are affected not only by poor energy performance, but they can also present structural deficiencies, considering that their design service life is exhausted in several cases.

Focusing on high-rise buildings in Leeds, the Leeds City Council (LCC) is strictly involved in retrofitting residential tower blocks with an over 10 years investment from 2016, in order to achieve the ambitious objectives of reducing both carbon emissions as part of the citywide target of 40% between 2005 and 2020 and tenants energy bills by 10%. LCC owns 116 apartment blocks which were widely built in '60s and the largest percentage of them are 10 to 12 storey high (Figure 6a and b). The majority of these constructions are reinforced concrete frames; however, some of them are constructed with a large concrete panel system (i.e. Reema, Cook, Myton and Shepard blocks). Some buildings have been improved through an extensive cavity wall insulation or an insulated cladding system. All these differences result in a wide variation of walls U-values which range from 0.34 to 1.56W/m^{2}K. Finally much of the heating infrastructure is outdated and in need of replacement (ARUP, 2016).

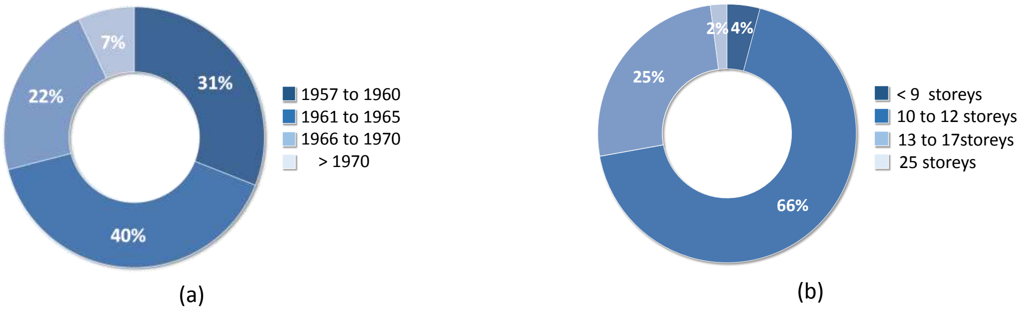


Figure 6. Share of Leeds tower blocks in terms of year of construction (a) and number of storeys (b)
(Data source: ARUP, 2016)

On that basis, an energy retrofit is highly required. The LCC has defined five recommended interventions in this direction with a scale of priority, ranging from 1 (high priority) to 4: a) community heating system (priority: 1); b) new hot water cylinder (priority: 1); c) new electric heater and controls (priority: 2); d) cladding - external wall insulation (priority: 2/3); increased roof insulation (priority: 4). This scenario results in a cost effective invest-to-save strategy, providing a balance between carbon saving and reduced energy bill. In such a way, energy efficiency is surely obtained, but the requalification is approached by a solving episodic problem exhibited by the building. Indeed, focusing exclusively on a single problem makes retrofit intervention limited to solving only part of the criticalities, without considering the complexity and the interrelation of all the deficiencies of the building system. Any retrofit solution which is conceived having in mind only one aspect, is bound to failure in a long term perspective. An integrated renovation based on the envelope retrofit could instead have the potential to improve the energy performance, ensuring at the same time several benefits related to the three dimension of sustainability. In that line, the Sustainable Integrated Retrofit (SIR) methodology could be applied in order to design and assess the best integrated retrofit solution.

Energy retrofit of Leeds tower blocks should be considered as a driver of renovation at urban scale. Indeed these tower blocks are often located in areas where there is no interaction between the built environment and the urban context. In addition, they exhibit a high state of deterioration, so interventions both on the fabric and on structure allow buildings to obtain architectural quality and structural safety, ensuring added property value and a global urban regeneration which means more liveability for the tenants and/or owners. In such a way, several environmental, economic and social benefits could be achieved: energy efficiency, as well as a reduction of CO_2 emissions; optimization of costs; health and well-being of the inhabitants. In addition retrofit for the life cycle becomes a way to assess future impacts of the renovated building already at the retrofit design phase, making decisions that will affect the next stages of building life-cycle and it also becomes a tool to protect environment, control costs, and ensuring human wellbeing. All that considered the SIR methodology perfectly suits the challenge of renovation, becoming a potential urban strategy which regards the implementation of energy retrofit in a holistic process for Leeds tower blocks upgrading.

CONCLUSION

A high quality of life, the reduction and recycling of waste, a more efficient use of water and energy and the management of the pressure exerted by demographic growth and urbanization are the major goals for a sustainable urban vision. In the light of the current state-of-art related to EU CO_2

emissions reduction and energy saving, energy retrofit of residential building stock turns out to be a potential solution in order to reach these objectives. Nevertheless many other requirements related to environment, economy, society as well as structural engineering should be considered for existing buildings, so an integrated renovation is needed.
In that line, an energy retrofit approach focused on the building envelope by using prefabricated modular systems results a conceivable solution to enlarge retrofit measures to the whole building. A potential sustainable integrated retrofit methodology is recommended and briefly introduced, exhibiting several advantages if applied to a real case study which refers to residential towers blocks in Leeds. In such a way, the challenge of energy improvement for those specific high-rise residential buildings offers the opportunity to reach a renovation at urban scale.

References

ARUP (2016) **Leeds City Council - Energy efficiency study for high rise flats - Investment Strategy Report.** REP/1/Strategy (20 January 2016).

BPIE - Building Performance Institute Europe (2011) **Europe's building under microscope - A country-by-country review of energy performance of buildings.** [Online]. BPIE report, Brussels. Available at: http://www.bpie.eu [Accessed 5 May 2017].

Brundtland, G.H. (1987). **Our common future**. Report of the World Commission on Environment and Development. Oxford: Oxford University Press.

Ciutina, A., Ungureanu, V., Grecea, D. and Dubina D. (2013). Sustainable thermal retrofitting solutions for multi-storey residential buildings. In: V. Ungureanu and L. Fülöp (eds) **Romanian – Finnish Seminar on Opportunities in Sustainably retrofitting the large panel reinforced concrete building stock**, Timisoara: Orizonturi Universitare, pp. 97-112.

Department of Energy and Climate Change – DECC (2014). **Digest of United Kingdom Energy Statistics 2014**. [Online]. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/338750/DUKES_2014_printed.pdf [Accessed 7 May 2017].

Entranze project, Intelligent Energy Europe Programme (2013-2017) **Entranze data tool** [Online]. Available at: http://www.entranze.eu/tools/interactive-data-tool [Accessed 7 May 2017].

European Commission (2012). **Energy-efficient buildings PPP beyond 2013 - Research and Innovation Roadmap**. Document for E2B European Initiative (ECTP). [Online]. Available at: http://ectp.ectp.org/cws/params/ectp/download_files/36D2431v1_E2B_Roadmap_21-le 11_rev3.pdf [Accessed 7 May 2017].

European Commission - Cordis (2012) **Envelope Approach to improve Sustainability and Energy efficiency in Existing multi-story, multi-owner residential buildings project - EASEE**. Final report. [Online]. Available at: http://cordis.europa.eu/result/rcn/186986_en.html [Accessed 5 May 2017].

European Commission - JRC (Joint Research Centre) (2012) **Reference Document on Best Environmental Management Practice in the Building and Construction Sector**. Final Report (EMAS regulation Article 46.1). September 2012.

Griffin, C. (2016) Multi-performance retrofits to existing buildings: Increasing resiliency and reducing the environmental impact of buildings through simultaneous structural and energy retrofits. In: J. Goggins (ed.) **Proceedings of Civil Engineering Research in Ireland 2016 (CERI2016) Conference**, 29-30 August 2016, Galway: CERAI, pp.7-13.

International Energy Agency - Energy Conservation in Building & Community Systems, IEA - ECBCS (2011) **Prefabricated Systems for Low Energy Renovation of Residential Buildings IEA ECBCS Annex 50** [Online]. Available at: http://www.ecbcs.org/annexes/annex50.htm

Iuorio, O., Barbalace, A., Fernandez F. (2016) Retrofit opportunities for the Historical Back Bay Neighbourhood. R. P. Borg, P. Gauci and C. Spiteri-Staines (eds) **SBE16 Malta Europe and the Mediterranean Towards a Sustainable Built Environment**, Malta: SBE Malta - Sustainable Built Environment, pp. 419-425.

Kamel, E. and Memari, A. M. (2016) Different methods in Building Envelope Energy Retrofit. In: A. Memari and S. Klinetob Lowe (eds) **3rd Residential Building Design & Construction Conference**, Penn State, University Park, 2-3 March 2016. [Online]. Pennsylvania: The Pennsylvania Housing Research Center - PHRC, pp.64-84. Available at: http://www.phrc.psu.edu/Publications/2016-RBDCC-Papers.aspx [Accessed 7 May 2017].

Landolfo, R., Cascini, L. and Portioli, F. (2011) Sustainability of steel structures: towards an integrated approach to lifetime engineering design. **Journal of Frontiers of Architecture and Civil Engineering in China,** 5(3) September, pp. 304-314.

Marini, A., Passoni, C., Riva P., Negro, P., Romano, E. and Taucer, F., (2014) **Technology options for earthquake resistant, eco-efficient buildings in Europe: Research needs.** European Commission, JRC Scientific and Technical Research, Report EUR 26497 EN, Luxembourg: Publications Office of the European Union.

McKinley, K. (2012) Business sustainability - The right cause for the right reasons. **ISO FOCUS - the Magazine of the International Organization for Standardization: Sustainability**, 3(1), pp. 13.

Musa, B. T. and Alibaba H. Z. (2016) Evaluating the Use of Double-Skin Facade Systems for Sustainable Development. **International Journal of Recent Research in Civil and Mechanical Engineering** [Online], 2(2) October, pp. 151-159. Available at: www.paperpublications.org [Accessed 5 May 2017].

Romano, E., Negro, P. and Taucer, F. (2014) **Seismic performance assessment addressing sustainability and energy efficiency.** European Commission, JRC Scientific and Policy reports, Report EUR 26432 EN, Luxembourg: Publications Office of the European Union.

Romano, E., Cascini, L., D'Aniello, M., Portioli, F. and Landolfo, R. (2015) Improving sustainability performance of existing buildings: a case-study. In: A. Caverzan, M. Lamperti Tornaghi, P. Negro (eds), **Proceedings of SAFESUST Workshop, European Commission - Joint Research Centre, Ispra, 26-27 November 2015.** Luxembourg: Publications Office of the European Union.

Sarja, A. (2003) A process towards lifetime engineering in the 5th and 6th Framework Program of EU. In: **2nd International Symposium ILCDES 2003: Integrated Lifetime Engineering of Buildings and Civil Infrastructures**, Rotterdam, pp.1001-1006.

Sartori, I. and Hestnes, A.G. (2007) Energy use in the life-cycle of conventional and low-energy buildings: a review article. **Energy and buildings**, 39, pp.249-257.

United Nations, Department of Economic and Social Affairs - Population Division (2014) **World Urbanization Prospects: The 2014 Revision, Highlights** (ST/ESA/SER.A/352). [Online]. Available at: https://esa.un.org/unpd/wup/publications/files/wup2014-highlights.Pdf [Accessed 7 May 2017].

United Nations, Department of Economic and Social Affairs - Population Division (2016) **The world's cities in 2016 - Data booklet** (ST/ESA/ SER.A/392). [Online]. Available at: http://www.un.org/en/development/desa/population/publications/pdf/urbanization/the_worlds_cities_in_2016_data_booklet.pdf [Accessed 7 May 2017].

Zhang, X., Shen, J., Lu, Y., He, W., Xu, P., Zhao, X., Qui, Z., Zhu, Z., Zhou, J. and Dong, X. (2015) Active Solar Thermal Facades (ASTFs): From concept application to research questions. **Renewable and Sustainable Energy Reviews** [Online], 50, October, pp. 32-63. Available at: http://www.sciencedirect.com/science/article/pii/S1364032115003780 [Accessed 3 May 2017].