Sustainable Refurbishment for an Adaptable Built Environment

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ABSTRACT **The reconsideration of the existing building stock is motivated by society's efforts towards sustainability and resilience. The building sector has a considerable role to play in doing so. The process of refurbishment is complex, since aspects such as design decisions, existing construction, energy efficiency, and user behaviour need to be considered. The motivation for refurbishing existing buildings is related to environmental, social, and economic aspects of their use or reuse, which are the three core aspects of sustainability. The key environmental motivation is to reduce energy consumption from fossil fuels and related greenhouse gases (GHG) emissions, and to include energy generation from renewables; the key economic motivation is to lessen the cost of energy used for heating, and the key social motivation is to reduce fuel poverty and improve the quality of life and well-being of the occupants.**
This chapter aims to explain the role of refurbishment of the building stock for sustainability and resilience. Firstly, definitions of the levels of building upgrades are given, and the motivations for refurbishment are discussed. Furthermore, the ecological, economic, and social aspects of refurbishment are deliberated on, together with the importance of the building stock for resilience. Finally, case studies of refurbishment projects are presented, providing insights into different aspects of refurbishment for sustainability and resilience.

KEYWORDS refurbishment, retrofit, existing buildings, sustainability, resilience

1 Introduction

The term 'sustainable development' was defined by the World Commission on Environment and Development (WCED, 1987) in its report 'Our Common Future'. The key principle of sustainable development is that it can only be achieved if socio-economic development is based on the responsible use, preservation, and renewal of the Earth's limited natural resources, and the use of renewable resources. Moreover, the report focused on global realities and recommended urgent action on eight key issues that ensure sustainable development. One of those key issues addressed by the WCED is energy (UNESCO, 2003).

The United Nations Conference on Environment and Development, held in Rio de Janeiro in June 1992, outlined the principles of future global sustainable development (UN, 1992). The principal output was Agenda 21, which determined priority actions and provided guidelines for their achievement. Agenda 21, a guiding philosophy for global sustainable development, served as the basis for subsequent international agreements related to global environmental, social, and economic problems.

More recently, in December 2015, the Paris agreement at the Climate Conference (FCCC/CP/2015/L.9, 2015) stressed the urgency to respond to the threat of climate change by keeping the global temperature rise less than 2 degrees Celsius above pre-industrial levels this century, and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. Within the scope of this agreement, stakeholders and authorities will need to further reduce their emissions and build resilience to decrease vulnerability to the effects of climate change (European Commission, 2015). This is in line with the long-term commitment of the European Commission (2013) to the decarbonisation path, with a target for the EU and other industrialised countries of 80 to 95% cuts in emissions by 2050.

The use of energy is the main source of greenhouse gases (GHG) (Eurostat, 2012, 2015). As the energy consumption of the building sector accounts for approximately 40% of final energy consumption in the EU (Eurostat, 2013), the importance of the building sector is recognised and addressed by institutions and legislative parties. Next to the energy use, the construction and operation of buildings have significant financial and social implications. Thus, a sustainable building should consider "design and construction using methods and materials that are resource efficient and that will not compromise the health of the environment or the associated health and well-being of the building's occupants, construction workers, the general public, or future generations" (Landman, 1999, p. 7).

The built environment is relevant to sustainability. The interest of legislative parties and the EU in particular, in the building sector confirms this importance. Together, the Energy Efficiency Directive (DIRECTIVE, 2012/27/EU) and the Energy Performance of Buildings Directive (EPBD) determine the framework for member states to promote the reduction of energy use in buildings (BPIE, 2013). Given the importance of existing buildings, sustainable refurbishment aims at achieving the goals of sustainable development by addressing environmental, social, and economic aspects. Research has shown that more energy conservation and other sustainable benefits can be achieved in the existing building stock compared to newly-built buildings (Itard & Meijer, 2008).

Refurbishment already represents a significant share of building construction practice with approximately half of the total turnover of major repairs (Thomsen, 2010; Genre, 1996; Flourentzou, Genre, & Roulet, 2001; McGraw-Hill Construction, 2011). The building industry, including architects, contractors, product suppliers etc., is already working on upgrading existing buildings. Nevertheless, sustainability benefits, such as energy savings, is rarely the sole motivation for refurbishment. Usually, the decisions are interconnected with other financial and social motivation. Whatever the motivation, the challenge for the design of the refurbishment strategy is to incorporate strategy measures that improve the sustainability and resilience of the refurbishment.

This chapter aims at explaining the role of the refurbishment of the building stock for sustainability and resilience. Firstly, definitions of the levels of building upgrades are given, and the motivations for refurbishment are discussed. In addition, the chapter deliberates on the ecological, economic, and social aspects of refurbishment. Finally, case studies of refurbishment projects are presented, providing insights into different aspects of refurbishment for sustainability and resilience.

2 Definitions of Refurbishment

Refurbishment as a term used in the building sector can cover a broad range of measures. Different terms may apply, depending on the degree and type of intervention, from repairs and maintenance to demolition and reconstruction. Fig. 2.1 summarises the various levels of intervention, from smaller to bigger interventions.

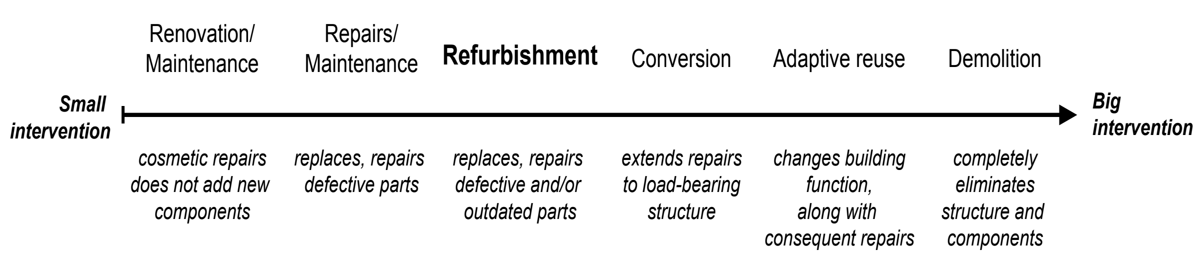

FIG. 2.1 Degrees of intervention on buildings *(Konstantinou, 2014)*

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The refurbishment level ranges from repairs/maintenance to conversion. Maintenance is restricted to replacement or repair of defective components. Conversion would affect load-bearing building elements and interior layout. Refurbishment, on the other hand, does not include major changes in the load-bearing structure. In refurbishment, defective parts, as well as outdated components or surfaces, are repaired or replaced (Giebeler et al., 2009). Upgrade of fire protection, acoustics, and thermal performance can, therefore, be achieved through refurbishment. Additionally, during the refurbishment, buildings can be retrofitted with technologies for energy generation from renewable sources.

The Energy Performance of Buildings Directive (EPBD) applies the terminology of "major renovation". Existing buildings, building units and building elements that undergo major renovation need to reach specific requirements for the energy performance. EU Member States should define major renovation as measures in which the total cost of the renovation relating to the building envelope or the technical building systems is higher than 25% of the building value, or more than 25% of the surface of the building envelope undergoes renovation (DIRECTIVE, 2010/31/EU).

An interpretation of major renovation, which is related to sustainability and GHGs, is the term "deep renovation". The refurbishment depth is related to the level of savings on energy or greenhouse gas emission, specifying as "deep" such renovations that achieve energy savings of 60-90% (BPIE, 2011). Typically, a holistic approach that considers a package of measures is required to reach deep renovation savings. Superficial renovations with lower savings in energy consumption obstruct the climate targets fulfilment, as they can result in huge potential savings to remain untapped (Hermelink & Müller, 2011).

3 Sustainable Refurbishment

Motivations for refurbishing existing buildings are related to environmental, social, and economic aspects of their use or reuse, which are the three major categories of sustainability (Emad & David, 2012; Munasinghe, 2004; Nahmens & Ikuma, 2012). As refurbishing a building is a complex process that encompasses parameters such as the architectural design and construction, energy efficiency, socio-financial effects, and user behaviour, it is understandable that it can affect all different aspects simultaneously.

The key environmental motivation is to reduce energy consumption from fossil fuels and related greenhouse gases (GHG) emissions, and to include power generation from renewables; the key economic motivation is to reduce the cost of energy used for heating; the key social motivation is to reduce fuel poverty and improve quality of life and well-being of the inhabitants.

3.1 Environmental Aspects

Reduction of GHG emissions by improving energy efficiency of buildings
The building stock has been the central focus of policies for energy saving. The International Energy Agency (IEA) has identified the building sector as one of the most cost-effective sectors in the reduction of energy consumption, with an estimated possible energy saving of 1,509 million tonnes of oil equivalent (Mtoe) by 2050. Moreover, improving energy efficiency in buildings and, hence, reducing overall energy demand, can significantly reduce building-related carbon dioxide (CO2), translating to possible mitigation of 12.6 gigatons (Gt) of CO2 emissions by 2050 (IEA, 2010).

Energy efficiency of existing buildings can be achieved by applying one or more measures that increase the thermal resistance of the envelope and improve the performance of the building services. Such measures include the replacement of windows with new, state-of-the-art panes and frames, the addition of thermal insulation material to external walls and roof, and the replacement of existing heating systems with new ones with a higher coefficient of performance (COP), such as heat pumps. More details about passive and active measures and technologies can be found in Book 4 of this series.

Enabling generation of energy and hot water from renewable sources on refurbished buildings
Next to energy efficiency measures that reduce the energy demand and the related GHG, existing buildings can also act as power generators for electricity and hot water. The envelope of the existing building or its surroundings can be used to accommodate photovoltaic and solar panels, and retrofitted building services can use energy from renewable sources. More details about renewable energy technologies can be found in Book 4 of this series.

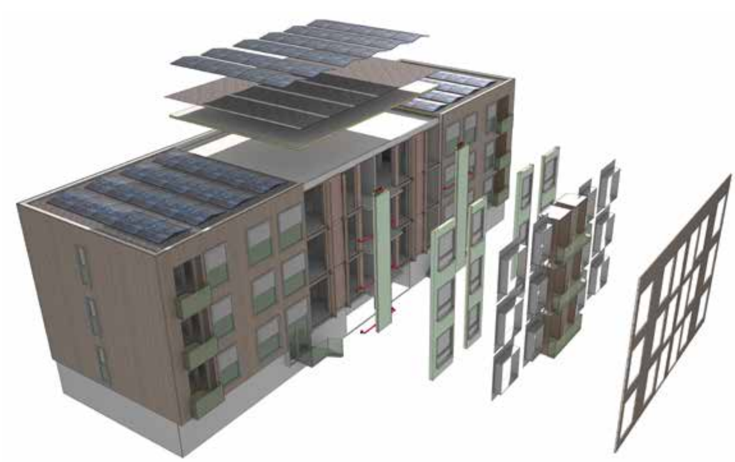


FIG. 3.1 Example of the 2ndSkinzero-energy refurbishment concept *(Konstantinou, Guerra-Santin, Azcarate-Aguerre, Klein, & Silvester, 2017)*

Combining measures to improve energy efficiency and generate energy has the potential to provide zero-energy refurbished buildings, such as in the approach presented in Fig. 3.1. The built environment can only be transformed to zero-emission by eliminating the buildings' consumption of energy generated from fossil fuels.

Saving natural resources by applying circular economy principles in refurbishment

To achieve strong energy performance in new constructions, which includes better insulation and efficient building services, new buildings require major energy, carbon, and wider environmental impacts, due to the demand in new materials (Power, 2008). Preserving and transforming existing buildings is more environmentally efficient than demolition and rebuilding, as natural resources are saved. The building process and the new materials used are energy intensive, while most of the building structure and building components in an existing property rarely need replacing. Consequently, new buildings require four to eight times more resources than an equivalent refurbishment (Itard & Klunder, 2007). Regarding broader environmental impact, demolition and building are a major source of landfill volume, accounting for around 30% (Power, 2008). Fig. 3.2 shows some examples of waste from building components. Therefore, the reduced availability of landfill sites also has implications for the scale of building and demolition, and limiting waste through reuse, refurbishment, and recycling is needed.

A

B

FIG. 3.2 (A) Waste from building components and (B) recycling plant of building components

3.2 Economic Aspects

Embodied energy and capital
Buildings also store capital, bound to the raw materials. While façades and building services may reach the end of their technical lifespan at the age of 30 years, the load-bearing structure can last for a century or more. Thus, demolition would not only be a waste of embodied energy and energy used for demolition, but also a waste of capital.

Reducing cost of energy consumed for heating and hot water
The operational cost of a building is strongly related to its energy consumption. The general trend is for energy prices to rise, despite some intermittent falls, which are often mitigated in the retail price by increasing related taxes (IEA, 2016; ITRE, 2015). The energy price rise directly leads to higher operational cost. Considering that tenants would accept higher rental rates if the operational costs were lower, refurbishment has a direct economic effect on improving energy efficiency and reducing the energy consumption of the building. The report "Europe's buildings under the microscope" (BPIE, 2011) estimated that deep renovation of the building stock to reach the 2050 targets may result in €380 billion savings for consumers, with direct positive effects on fuel poverty, as will be discussed in the following section as part of the social aspects.

Reducing cost by reusing existing building materials and components
From a financial point of view, demolition and new construction make sense if only minor renovation with little energy saving is possible, and if a building is in such bad state that extensive, cost-intensive, non-energy related measures are needed. In addition, the energy performance of a renovated building could be equal to that of a new building. Thus, the argument that the lifespan expectation and market position of a renovated building can be insufficient to justify the investment is not convincing (Thomsen & van der Flier, 2008).

Strengthening economic resilience by increasing the commercial value of refurbished buildings and their attractiveness to the market
The planning of a refurbishment project offers the opportunity to improve the performance and function of the building, as well as to increase the usable space by making the internal layout more efficient or by constructing additions and extensions to the building. The added usable space has an immediate result in the form of an increase in the commercial value of the building. Furthermore, high energy efficiency and sustainability features promote a green and renewed image of the property, which makes it more attractive to potential buyers and tenants.

Job creation
Finally, refurbishment activities can contribute to job creation. Particularly in the residential sector, employment gains are typically higher than in other sectors (Waide, Gurtler, & Smith, 2006). It is estimated that around 1 million jobs can be created annually throughout the period until 2050, as a result of deep renovation of the residential building stock (BPIE, 2011)

3.3 Social Aspects

Increasing social resilience
Demolition, as an alternative to renovation, is slow, costly, and unpopular. It provokes community opposition among the very people who are supposed to benefit from the measure (Power, 2008), as those living in locations targeted for demolition often have little say in the deposition of their neighbourhood and often face difficulty in finding replacement housing (Crump, 2012).

Reducing fuel poverty
Reduced energy demand results in lower energy bills for the people living in refurbished dwellings. With 10-25% of the total EU population estimated to be fuel poor, energy efficiency upgrade of residential buildings can provide the means for reducing fuel poverty as a result of lower energy bills following such renovations (BPIE, 2013).

Improving the quality of life of building occupants
Apart from the resulting savings in energy use and the consequent mitigation of climate change, an immediate effect of energy efficient refurbishment is improved comfort and increased building quality, both functionally and technically. Refurbishment can be decided on the grounds of reduction of noise or draught. Retrofitting of building services, replacement of windows, and restoration of damaged components are some measures to improve technical quality as well as the comfort in such spaces.

Functional shortcomings, such as small apartment size, inadequate space layout, and lack of accessibility for people who have temporary or long-term physical impairments, are also major issues that impair quality of life, and which refurbishment can address. Over the years, the average number of persons per dwelling has decreased from 5-6 in the early post-war years to 2.43 persons per dwelling in 2002 (Andeweg, Brunoro, & Verhoef, 2007). It is thus evident that updates in the layout and number of houses are necessary. Accessibility is also important, particularly with the shift in the age profile of the European population (BPIE, 2011). Housing built prior to the 1960s was not equipped with elevators, even in three or five-storey buildings. The refurbishment strategy can incorporate these functional improvements.

Preserving socio-cultural context of importance to the community
Refurbishment also serves to preserve the societal value of existing buildings, together with their cultural and historical value, while improving living conditions. When buildings today are in need of refurbishment, the task is to keep their history alive and preserve their value for society. In practice, this means that each project has to be valued for its qualities and potentials. Urban areas that are considered as important architectural and urban heritage may be designated as conservation areas in which only visually sensitive refurbishment is permitted, and demolition and rebuilding allowed only if it has been ascertained to be the only viable option. In urban areas that do not have exceptional architecture, good quality refurbishment can improve the

appearance of buildings and streets. Overall, refurbishment can preserve as well as promote the design qualities and socio-cultural values of a building, a street, or a neighbourhood atmosphere, as well as the heritage value of buildings and cities, as in the example shown in Fig. 3.3.

FIG. 3.3 Archipelbuurtdistrict in The Hague, NL. The district has preserved its original character.

Improving the appearance, attractiveness and safety of the built environment

Technical decay in buildings is related to social decay (Priemus, 1986). Strong socio-economic user groups leave buildings that are technically and functionally outdated, and weaker groups replace them. This process often results in a high turnover of tenants, vacancy, lack of control, and generally "unfavourable" living conditions. Refurbishment can, hence, stabilise an uncertain social environment, as the renovated buildings meet today's demands and provide a functional and attractive contribution to society. Such an example is the residential complexes in the Bijlmermeer district in Amsterdam (Fig. 3.4)

FIG. 3.4 Renovated ground floor apartments in the Bijlmermeerarea, Amsterdam, NL

4 Refurbishment Design for Future Adaptation

The study included surveying resilient design principles, and establishing building-related criteria (see Chapter 2 of this book). Grammenos and Russel (1997) define an adaptable building as one intentionally built so that changes in its use, expansion or contraction of space, or major changes to its systems and envelope can be accommodated with minimal waste of resources. The same principle should apply during the refurbishment of an existing building.

It is useful to make a distinction between the terms adaptability and flexibility of buildings. Designing for flexibility implies that a design brief requires building systems that can meet changing needs over time, both from minute-to-minute (as, for example, the building services respond to changes in the weather, internal heat gains, use, and occupant requirements), from day-to-day (with modifications in working patterns, space use, equipment, furniture etc.), and from time-to-time (with changes in organisational structures, requirements, tenancy and even function) (Bordass & Leaman, 1997). The first requirement implies that a building is highly serviced and may have sophisticated building management control systems. Complex building services systems that were initially intended to provide flexibility might themselves obstruct the change that is later found to be required. Harvey and Ashworth (1996) say that the more 'intelligent' the building, the more difficult it is to manage and reorganise because highly trained personnel are needed to carry out operations and replacement of systems. The alternative strategy may be to provide simpler, but potentially adaptable, buildings, which are easily altered as needs change, and to apply the same approach during the refurbishment of an existing building. If complexity is necessary, it should be isolated and managed by simple interfaces (Bordass & Leaman, 1997). Some buildings may not have such systems because they were not required for the initial buildings' uses. However, the design of adaptable buildings and refurbishment of existing buildings should provide a spatial capacity for the installation of additional services in the future.

In the design of more conventional buildings, which are envisaged as non-demountable and durable, but need to be adaptable, the main difficulty lies in predicting what types of space, structures, and services lend themselves to change. Although predictions are difficult, Ozbekhan (1969) points out the importance of being able to distinguish between what is constant and what is variable. Basic physical elements by which a traditional building can be defined are structure, enclosure, stairs, and services. The question is whether they are constant or variable. Some buildings have been planned with demountable structures, which may be considered as a variable feature. However, the structure of most buildings can be regarded as a constant until the end of the building life. Normally, enclosure and vertical circulations are designed as permanent features, intended to last throughout the building's life. Nevertheless, they can be and have been changed on some buildings. Design for Disassembly (DFD) is a trend in manufacturing that will introduce more variable features in building design. The need for services can be considered a constant, but their type and technological solutions not necessarily so.

Russell and Moffatt (2001) define three design strategies for adaptability: flexibility or enabling minor shifts in space planning; convertibility, or allowing for changes in use within the building; and expandability (alternatively shrinkability), or facilitating additions to the amount of space in a building. They provide a broad-brush description of desirable characteristics of foundations, superstructure, envelope, services, and interior spaces, which can enable easier adaptations. Langford, MacLeod, Dimitrijevic, and Maver (2002) developed the criteria for assessing a potential for adaptation of new and existing buildings. The criteria consider exterior spaces (building site); interior space (size of spaces/rooms, relations between them, and to the circulation routes in the layout); accessibility of the building site and existing infrastructure; spatial and structural characteristics; capacity of services, the possibility of enlargement of that capacity, and the space available for their maintenance and replacement.

According to Burns (1992), clients would like a structure that allows for flexibility and adaptability, but often are unwilling to spend additional money to achieve this in the initial design. However, they are beginning to expect adaptability to be part of the structural design of a building and refurbishment, given the greater uncertainty associated with the future property market (Burns, 1992). Kohler (1999) points out that instead of minimising the investment cost through low-cost highly customised solutions, an investment benefits from identifying the solution with the highest durability and reusability. An analysis of the investments for adaptations during the lifetime of buildings is needed to support design for adaptability. Grammenos and Russel (1997) refer to studies of hospital buildings that have shown that the capitalised costs of alterations over a typical ten-year period equalled the original capital cost.

The durability, adaptability, and energy conservation (DAEC) tool developed by Langford et al. (2002) enables the input of estimated costs of examined design features in the adaptability assessment. Two estimates for each design feature are provided: first, the initial costs, and second, the costs of providing the same features, if possible, after the building has been built. The comparison of the difference between the initial and later costs assists in deciding on the investment. Examining whether some design features could be provided at all after the building has been built may help in deciding if they need to be provided initially. Another aim of the comparisons is to assess whether the added costs for elevated adaptability can be justified on the basis of the avoided costs of alterations or demolition plus new construction (Grammenos & Russel, 1997).

5 Challenges and Barriers

Despite the motivation to continue using and renovating existing buildings, the EU average renovation rate is as low as 1%, and renovations are mainly minor. Barriers related to finances, institutional issues, awareness, advice and skills, and the separation of expenditure and benefit prevent or delay the uptake of renovation measures (BPIE, 2011).

Financial barriers are at the top of the list, as any renovation requires an investment. Deficiency of funds is the most reported reason that prevents investment in energy efficiency. Despite the fact that the measures are cost-effective in the long run, the initial investment cost is often an obstacle for the decision. Furthermore, energy cost is not a major concern for the majority of consumers. It represents a small share of household or company expenditure – an average of 3-4%, which can be higher in low-income households (BPIE, 2011; Drehobl & Ross, 2016) – and the payback period of the energy savings may exceed the occupancy period. In order to support decisions for energy upgrades, several financial instruments are necessary, such as grants, preferential loans, VAT reduction, penalties if minimum requirements are not met, and the financing of energy service companies. Alternative business models, e.g. the Product-Service System (PSS) for façade renovation proposed by Azcarate-Aguerre, Klein, and den Heijer (2016), also have the potential to tackle the high initial investment.

The lack of adequate advice and technical expertise is another concern that hinders renovation (BPIE, 2011). Existing building interventions require different skills than large-scale new construction regarding technical, social, and managerial craftsmanship, on top of different type, size, and organisation of the company. This observation applies to designers, developers, commissioners, and governments, whose knowledge about how and when to effectively maintain, adapt, transform, and redesign older stock still needs to improve (Thomsen, 2010). Even though energy savings are generally appreciated as a renovation effect, there remains a lack of understanding of the potential energy, cost, and carbon savings resulting from different measures.

Finally, a complex barrier is the separation of expenditure and benefit, also referred to as the "split incentives barrier" (BPIE, 2011).In cases when one party owns the building and is requested to invest in energy efficiency, while another – the tenant – benefits from the resulting energy saving, such split incentives occur. It is not easy to overcome this barrier. A combination of measures and policies is needed, such as regulatory instruments for energy efficiency standards for appliances and buildings, availability of reliable information about energy performance (IEA, 2007), as well as potential changes in the current transaction structure. These options are based on complex interactions, but may be combined into integrated policies that reduce energy-related emissions (Barrett, Lowe, Oreszczyn, & Steadman, 2008). Examples of such policies are the Green Deal in the UK, which spreads the costs of the energy efficiency improvements over the lifetime of the installed upgrade (Crawford, Johnson, Davies, Joo, & Bell, 2014), or the

Energy Performance Subsidy - Energieprestatievergoeding (EPV) in the Netherlands, which allows the landlord to ask for an additional amount of rent per m^2 for nearly zero energy buildings (RVO, 2016).

6 Best Practice

Despite the barriers discussed above, there are many successful examples that incorporate physical, aesthetic, and functional upgrades, while taking into account the occupants' needs and the architectural value of the building. Such concerns are necessary to address sustainability and resilience aspects.

This section presents three best practice refurbishment projects in different European countries. Each one had different concerns and objectives, but all resulted in solutions that improved the environmental, economic, and social value of the building.

6.1 Renovation and Transformation of a Residential Building in Klarenstraat, Amsterdam-Slotervaart, NL. Architect: Vanschagen Architecten

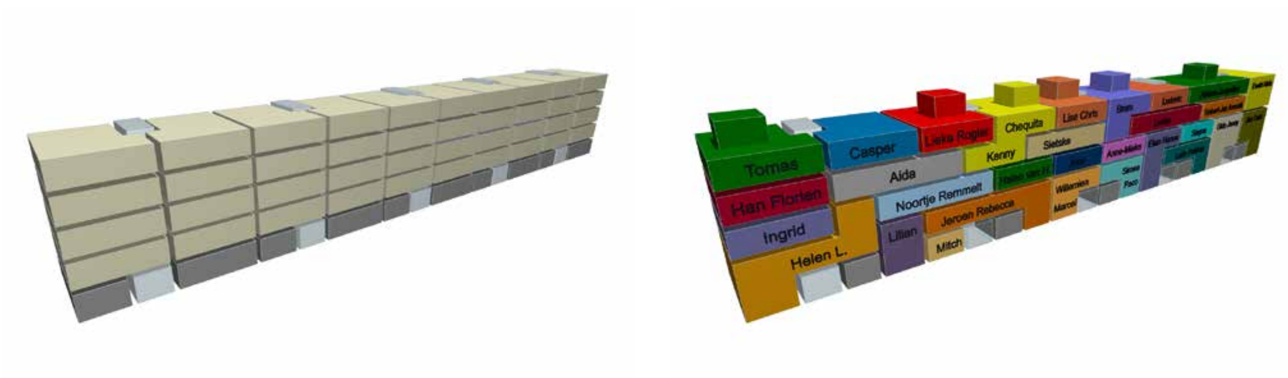
During the transformation of a tenement building in U.J. Klarenstraat, in the district of Amsterdam-Slotervaart, the buyers of the apartments, together with the architect and the housing association that owned the building originally, developed not only the architectural interventions but also the business model that made this project possible. In this way, the process illustrates a new role for the designer and the owner in renovation projects.

A

B

FIG. 6.1 The original (A) and the refurbished (B) apartment building in Klarenstraat *(Photo: courtesy Vanschagen Architecten)*

The original building was a typical example of a mid-rise, post-war, multi-family residential block, built in 1956 by architect Groosman (Fig. 6.1.a). It consisted of 40 identical apartments of 75m² each. On the ground floor, a storage and parking area was located. The transformation had a big effect on the occupants and ownership of the building on different levels. Firstly, the status was changed from moderate-rent apartments to individual owner occupied flats. As a result, the character of the apartment type was now adjusted to fit the needs of the new owners.



A *B*

FIG. 6.2 The layout of the renovated building. The 40 original identical apartments (A) were transformed into (B) 30 diverse apartments, ranging from 40 to 190 m² *(Photo: courtesy Vanschagen Architecten)*

The 40 original identical apartments were transformed into 30 diverse apartments, ranging from 40 to 190 m² (Fig. 6.2). Other improvements included the creation of private gardens on the ground floor, roof terraces, and new balconies, which were subject to owners' choice. Thus, the renovated building broke the prevailing pattern of the apartment blocks and complexes of the post-war period and demonstrated that it is possible to adapt to new standards of life and ownership.

Looking at the social aspects of the renovations, the new occupants' participation was critical for the transformation. Firstly, this was the first post-war tenement building renovation in the Netherlands that was assigned by a collective private client -collectiefparticulieropdrachgeverschap (CPO). Nowadays, this collective way of working has a positive effect on the way the building is inhabited as well as on the neighbourhood. Last but not least, the design process and the construction process were realised with the occupants' participation (Fig. 6.3). Once the general design layout and the basic structural interventions were completed, each owner could freely choose and construct the interior of their dwelling (Fig. 6.4).

Apart from the layout adaptations, the new owners had high ambitions in terms of energy efficiency. Even though each owner was given flexibility regarding the interior transformations, the building envelope insulation and the building services, including underfloor heating, were collectively upgraded to ensure high energy performance. Moreover, 250m² of photovoltaic panels were installed on the building. The interventions resulted in improving the energy label of the new dwellings from D/E to A, which constitutes a significant reduction in energy consumption (Rossem et al., 2017).

FIG. 6.3 The occupants involved in the renovation decision-making and participating in the construction work *(Photo: courtesy Vanschagen Architecten)*

FIG. 6.4 Interior of one of the apartments after renovation. Each apartment is different from the rest, not only in terms of size, but also due to the fact that the occupants made different design choices. *(Photo: courtesy Vanschagen Architecten)*

6.2 Transformation of 530 Dwellings, District Grand Parc, Bordeaux, FR. Anne Lacaton & Jean Philippe Vassal, Frédéric Druot, Christophe Hutin

The transformation of the three inhabited social housing buildings was the first phase of a renovation program of the 'Cité du Grand Parc' in Bordeaux. Built in the early 60s, this urban housing comprises more than 4,000 dwellings.

FIG. 6.5 The renovation process. The building exterior during the construction of the extension *(Photograph by Philippe Ruault)*

A

B

FIG. 6.6 A+B: Construction phases of the new structure *(Photograph by Philippe Ruault)*

FIG. 6.7 Original and renovated apartment block G in the Grand Parc district *(Photograph by Philippe Ruault)*

FIG. 6.8 The interior after renovation and extension *(Photograph by Lacaton & Vassal – Druot)*

The starting point of the renovation was to improve the usable interior space of the apartments, which in the pre-renovation state were considered to be small, dysfunctional and dark. As the apartments would stay occupied during the renovation process, the main intervention was proposed for the exterior. The renovated apartments open onto large winter gardens and balconies and offer pleasant 3.80m deep outdoor spaces; wide enough to be fully functional. Including the winter gardens, balconies, and storage spaces, the area of each dwelling increased significantly (Lacaton & Vassal, 2016). Fig. 6.5 and Fig. 6.6 show the construction phase on the winter gardens and extensions, which were realised externally while the dwellings were in an occupied state.

Interior improvement interventions and restructuring of the bathrooms were also suggested. The gardens surrounding the buildings were improved to facilitate access and use. Overall, the project dealt with the global performance of the building envelope, the reconfiguration of vertical circulation routes and access halls. As a result, the three 10 to 15-storey-high buildings gained a renewed architectural expression and appeal (Fig. 6.7) and the 530 dwellings that make up the buildings, were transformed into beautiful dwellings with redefined qualities and comfort. The new winter gardens and balconies provided more daylight, flexibility in their use, and views (Fig. 6.8).

Apart from the increase in the usable space and the improved quality of living, the renovation resulted in significant energy saving. The energy consumption was reduced by 66%, mainly as a result of the reduced heating energy demand in the renovated dwellings, which in the renovated apartments accounts for 20 kWh/(m2.a), while it used to be 116 kWh/(m2.a).

Concerning financial aspects, the cost of the new construction and renovation per dwelling was calculated to be less than 1/3 of the cost of demolition and rebuilding, proving the transformation a sensible investment, which was possible with no rent increase for the occupants. Moreover, the renovation took place while the building remained occupied, which offered financial benefits for the housing association and preserved the social coherence of the compound.

6.3 The Redevelopment of the National Museum of Scotland, Chambers Street, Edinburgh

The former Edinburgh Museum of Science and Art, opened in Chambers Street in 1866, was amalgamated in 1985 with the National Museum of Antiquities to create the National Museums of Scotland, and later expanded into a new building in 1998 (National Museums Scotland, n.d.).The aim of the redevelopment (undertaken in 2006-2011) of the Grade A listed building built in 1866, was to improve access for all, enhance visitors' facilities, provide new areas for displaying the museum's exhibits and improve energy efficiency (Gibb, 2012). Along with the conservation work (Fig. 6.9), the vaulted cellar spaces, previously hidden from public view, were excavated to form a new entrance hall (Fig. 6.10).

The strategy for improving energy efficiency had to consider a potentially very high cost for enhancing the thermal performance or air-tightness of historic façades, which in many areas would be practically impossible. One of the strategic approaches was to assign functions to each space in a way that made the best use of energy, building form, and structure. This principle was applied by displaying more resilient items in the Grand Gallery and more sensitive ones in 'sealed' zones deep within the building plan, protected from daylight and controlled with new heat recovery air-conditioning systems (Gibb, 2012).

Heating distribution and control systems were updated so that heating circuits could be monitored and controlled individually to reduce overheating and energy use. The latest low-energy lighting technologies such as LEDs and high-efficiency fluorescent lamps, and a system for automatic lighting control, were installed. The centralised energy metering system enables monitoring and reduction of energy consumption in each of the galleries and the extended storage and support spaces (Gibb, 2012).

The redevelopment of the Grade A listed building, which forms part of the National Museums Scotland, shows that the decisions concerning interventions to improve the energy efficiency of historic buildings must consider how to preserve building authenticity and avoid unacceptable costs by assigning the most suitable functions to specific spaces.

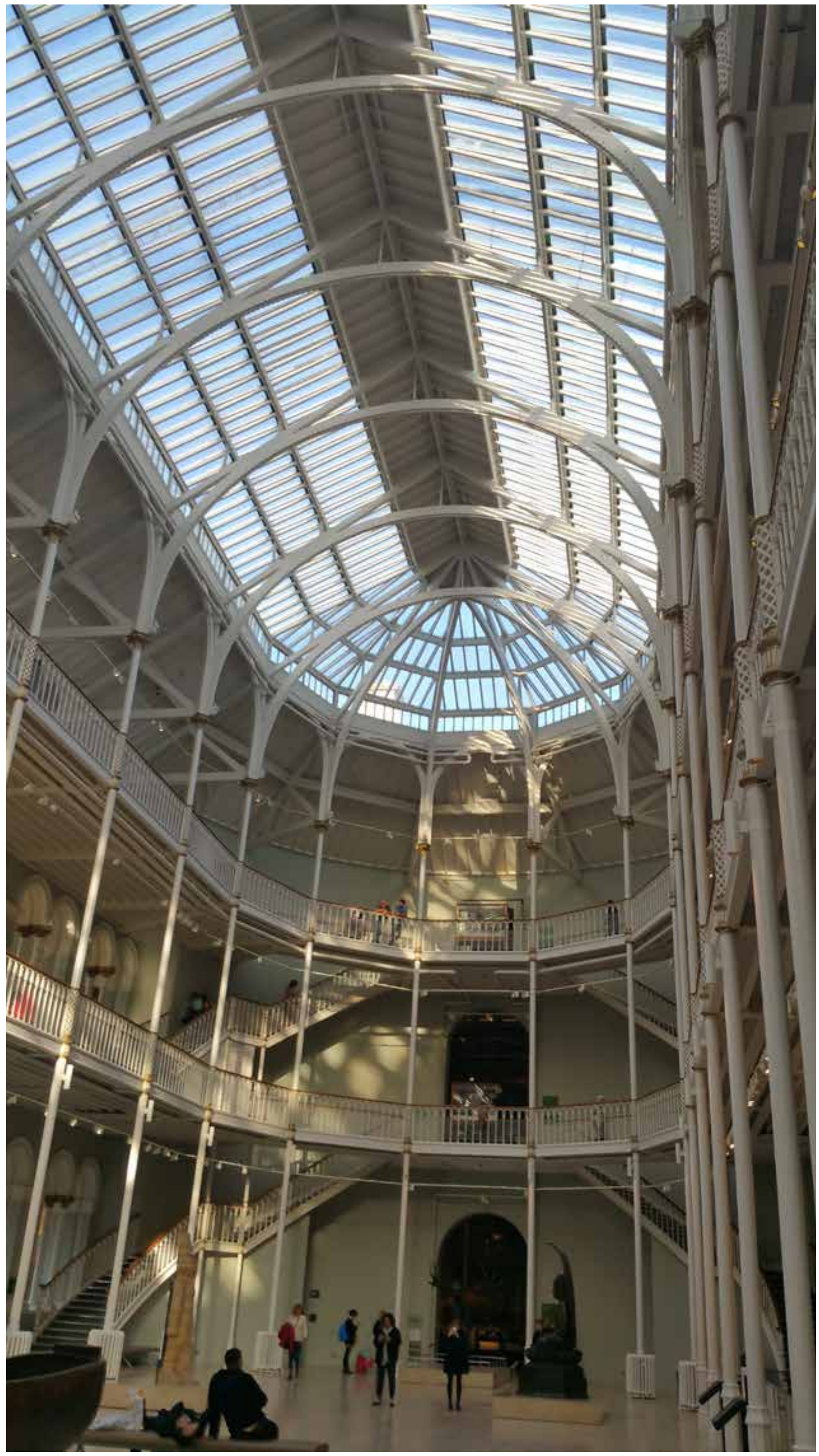


FIG. 6.9 Museum's Grand Gallery

This may mean that if the authenticity of a building (or some of its parts) is deemed more important than improving energy efficiency by adding thermal insulation (which can diminish a building's aesthetic qualities) or increasing air-tightness (which might be impossible or very expensive on some structures), such interventions will not be made. However, other energy efficiency interventions that do not have a negative impact on a building's aesthetics (e.g. more efficient lighting and control systems) should be considered.

FIG. 6.10 New entrance hall

7 Conclusions

Refurbishment is an integral part of buildings' life cycle, as components and functions become outdated or reach the end of their service life. Next to that, the upgrade of existing buildings presents an opportunity for achieving a more sustainable and resilient built environment. This chapter explained why refurbishment of existing buildings is related to sustainability and resilience, regarding the environmental, social, and economic effects it can have on the built environment and society in general.

The environmental aspects are primarily related to the reduction of energy demand and the resulting GHG emissions due to the improved energy performance of the building skin and services, as well as the possibility of integrating renewable energy sources in the refurbished building. Moreover, by reusing the existing building and extending its life, instead of demolishing it and building a new one, natural resources can be spared, which also offers financial benefits. Additional financial benefits are derived from the increase in the building value by the upgrade. Moreover, the improvement of the quality and the attractiveness of the buildings has, in turn, a positive effect on the quality of life and health of the occupants. The social and economic benefits extend as far as reducing fuel poverty, preserving the architectural and cultural heritage and creating jobs in the construction industry. Fig. 7.1 presents an overview of the sustainability aspects and the respective outcomes that sustainable refurbishment has.

It thus becomes evident that the benefits resulting from refurbishing the building stock cannot be strictly categorised in only one of the sustainability aspects, as they can be at multiple levels and the boundaries are blurred as the different aspects interact. Aspects of refurbishment are also demonstrated by the best practice examples, as well as multiple other examples of refurbishment practice, where the motivation and the result are never mono-dimensional.

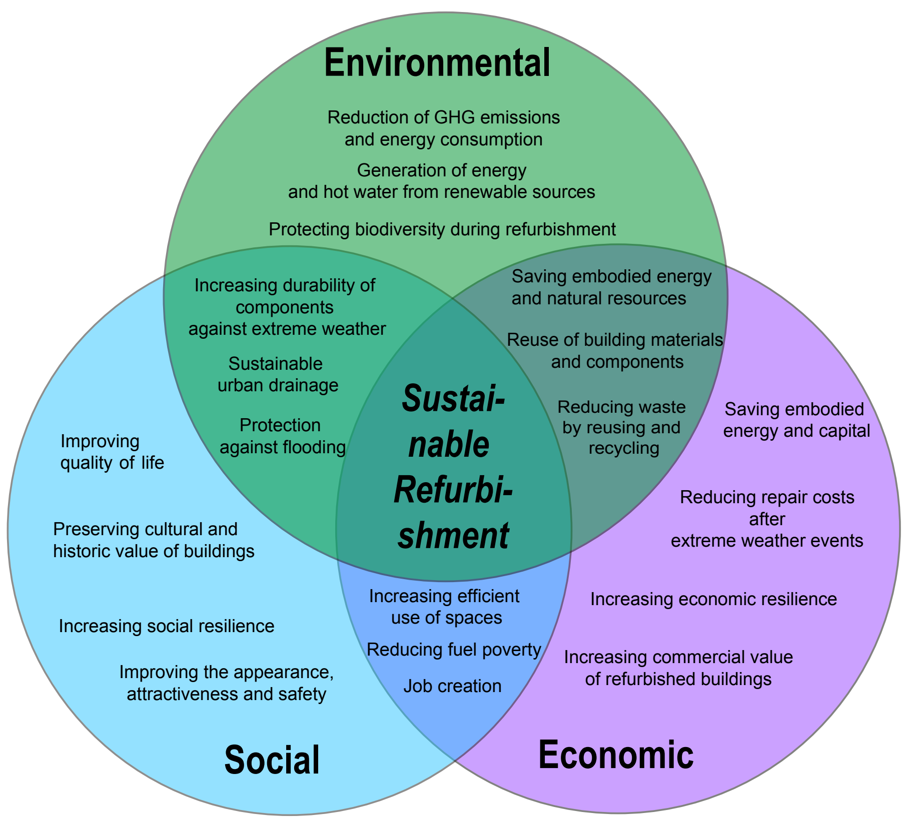


FIG. 7.1 Overview of refurbishment relevance to sustainability and resilience aspects

Taking into account all the positive aspects, it is understandable why refurbishment is a focal point in policies and directives. Overcoming the barriers to increase the rate and depth of renovation is a priority. Nevertheless, the key to the successful transformation towards a sustainable and resilient built environment lies within the building industry, and also depends on the architects, who should be aware of the challenges as well as the opportunities that the refurbishment of buildings presents, and who should make informed decisions towards their upgrade.

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