Adaptive Socio-Technical Devices _
Social Inclusion as a Rehabilitation Tool

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ABSTRACT **The complexity of the contemporary city is determined by socio-economic and demographic changes and by new energy standards that bring us to consider the rehabilitation of the building stock as a crucial and complex issue. The concept of sustainability requires an adaptive "integrated rehabilitation", in order to upgrade buildings not only from a structural, energetic, and architectural point of view, but also from a functional and social one. The research considers one of the most outdated sectors: residential multifamily buildings of the post-war years, which are today at the centre of a debate on their functional, security, and typological obsolescence. The need for urgent refurbishment, while avoiding demolition, brings us to consider the importance of additive strategies for regeneration, which include social, management, and financial feasibility. Some of those strategies are recognisable as "socio-technical devices": artefacts in which technical issues are strictly related to social ones, for the efficiency of the whole system. *Socio-technical devices* in building technologies for refurbishment allow us to manage the complexity of a construction site *au milieu habité*, facing the problems related to residential functions in the rehabilitation of multi-storey buildings. Starting from the definition of this concept, the research investigates, through the analysis of European case studies, new scenarios for renewal processes to prevent the breaking point of the city as a system, for a more resilient, adaptive, and bottom-up intervention strategy.**

KEYWORDS integrated rehabilitation, socio-technical systems, resilient and adaptive innovation, social innovation

1 Introduction

In the last decades, new requirements were added to the necessity of structural and energy upgrading of the most obsolete building sector. Those requirements were determined by urgent issues at the urban and architectural scale, caused by demographic, social, and economic changes. The progressive ageing of the population and urbanisation caused by several factors, such as rural migration to urban areas, led to a disturbance of the equilibrium in housing demand and supply, which in turn led to a consequent unavoidable reflection on strategies and methods.

According to the current standards, in fact, the approach of sustainability in architecture, design, and construction considers the whole life-cycle of the building, not only from an environmental point of view, but also from social perspective. The ISO/DIS 15392 – *Sustainability in building construction – general principles*, prescribes a "holistic approach".

Across Europe, a large part of the existing multifamily residential stock is no longer acceptable for energetic, structural, architectural, and functional reasons.

Some data can be found in the Research TABULA, *Typology Approach for BUiLding stock energy Assessment*, part of the European Program *Intelligent Energy Europe*, that has highlighted potential energy saving through the refurbishment of the multi-family buildings (built from 1946 to 1960). The neighbourhoods built after the Second World War encompass the typical examples of high density residential buildings in which architecture is characterised by quantitative needs, instead of qualitative requirements: heavy prefabrication building systems like *tunnel*, or *banches et tables* systems, show different kinds of typological and functional deficiencies (Zaffagnini, 1982; De Vita, 1965). Some of their characteristics, such as rigid space organisation, low architectural distinction among parts, limited recognisability of functions, and uniformity of the façades are seen as a lack of architectural quality: the results are monolithic blocks, which, in most cases, are no longer acceptable.

An illustrative example of those problems that determine the absence of flexibility, incorrect space dimensioning, and inattention to the social consequences of the architectural design process can be found in the case of the American neighbourhood of Pruitt Igoe, in St. Louis (USA). The demolition of this block, conducted in 1972, was recorded as the moment in which "modern architecture died", in the words of the historian Charles Jencks, who recognised in the event the breaking point of the *modern* way to conceive buildings and design neighbourhoods that was typical of rationalism (Jencks, 1977). The case of Pruitt Igoe is a story of architectural degeneration that implied a social deterioration, and it is comparable to different cases across Europe.

In Italy, examples of this can be found in the neighbourhoods of "il Corviale" and "Tuscolano" in Rome, "Rozzol Melara" in Trieste, "Le

Vele" in Naples, the "Gallaratese" in Milan, the "Zen" in Palermo, the "Pilastro" in Bologna and the "Forte Quezzi" in Genoa. In those neighbourhoods, new regeneration projects and research tried to address social problems connected to an old architectural set-up, which was no longer sustainable for social and constructive reasons.

In these circumstances, the issues of flexibility and adaptability must be considered as important instruments to be taken into account in order to select and implement the right strategy for refurbishment, considering social benefits next to the material ones.

In the dichotomy between *demolition* and *refurbishment*, the principle of sustainability leads us to prefer the latter, which offers more advantages from an environmental and social point of view: reuse, recycling, and restoration allow the limited use of new materials; on the other hand, refurbishment allows us to keep the dwellers' "habitat" unaltered, thus the community of inhabitants of the building preserves its usual organisation and functioning.

Under these circumstances, the refurbishment challenge is to recognise the appropriate applicable strategy that could take into account exigencies and realise a performance upgrade, as requested by actual European standards.

Among the renewal strategies, the additive methods are the most used today in integrating new performances into old buildings. In particular, the *Exoskeleton System* seems to be the most high-performance mode to carry out a holistic refurbishment. This method can be classified as a three-dimensional additive strategy that consists of volumetric expansions, structurally independent from the building, that provide structural, energetic, functional, and social upgrade. This is possible thanks to the possibility to extend on top of existing roofs, and additions to façades.

The aim of this section is to investigate the potentialities of socio-technical devices, such as the Exoskeleton System, for their important role in extending the concept of refurbishment to also meet functional and social demands. To address this issue, the chapter will analyse the requirements of obsolete buildings in comparison to future social changes in order to highlight the importance of new design qualities for the renewal of residential buildings. Starting from the definition of the *socio-technical device*, this innovative approach will be illustrated in some case studies, such as the Exoskeleton System.

2 Household Changes

Different European studies show that there have been important changes from the '50s to the present day, and even more mutations are projected up to 2080.

Society in Europe is progressively ageing. The Report of *Eurostat 2015* shows that the median age of EU-28's population has risen from 36.2 in 1994 to 42.2 in 2014. The projection for 2080 predicts a rise in the number of people aged over 85, which corresponds with the range of people who live alone: 13.4 % of households in these countries in 2013 comprise a single person family aged over 65, according to the *EU statistics on income and living conditions* (EU-SILC).

The continuous ageing of people combined with the necessity for autonomy and independence proves the demand of functional upgrades for building stock in terms of accessibility, inclusion, security, and comfort. At the same time, research shows a *change of household habits*: family units are deeply transformed with the spread of single-parent families, singles, co-habiting people, and large immigrant families (Delera, 2009; Malighetti, 2004; Piaia, 2009).

All of this leads to new social and functional needs that existing residential buildings can no longer answer. It is necessary to consider possible adaptable scenarios for refurbishment, which consider the complexity of the problem and the integration of different aspects in terms of *flexibility of internal organisation* and the introduction of *adaptive spaces*.

Flexibility and adaptability must be considered in both the long term and the short term: on one hand, there is a rise of dynamism in the family's structures (e.g. increase in number of divorces), while on the other hand, more dwelling spaces adaptable to new uses are necessary (e.g. working at home, teleworking, co-housing, etc.). The heterogeneity of habits and cultures also requires the adaptation of spaces due to diversity of cultures and, therefore, different ways of living.

Such issues indicate that, although energy saving measures or structural safety are largely recognised as priorities, functional deficiencies must also be taken into account. Among the requested performances for adaptive reuse, refurbishment, or maintenance are:

- *flexibility* in space and functions distribution (Cellucci & Di Sivo, 2016);
- *adaptability* of different spaces or devices for several, and unprecedented, uses; (Montuori, 2014; Wong, 2016)
- *accessibility*, *security,* and *inclusion,* for living conditions and building fruition.

Those requirements consider not only the technical performances of the building or its parts, but the whole space design and building process. For this reason, the evaluation of these qualities requests a holistic approach that considers the various aspects of design and the proactive maintenance of achieved qualities over time.

3 Architectural Prosthesis

Today, several studies look at additional strategies for refurbishment (Marini, 2008; Scuderi, 2015; Arenghi & Pane, 2016), specifically in relation to their implications in the modification of the city as an "urban metabolism". This term was coined to describe the urban ecosystem as a living organism, subject to energy and material flows (Decker, Elliott, Smith, Blake & Sherwood Rowland, 2000). In this scenario, several strategies can be found, which can be divided into increasing density strategies, such as *volumetric additions*, *grafting*, *filling,* and *roof-topping* and decreasing density approaches, such as *emptying*, *digging,* or *remodelage* (Castro & Denissof, 2005).

This diversity of approaches leads to the recognition of the refurbishment practice as a highly creative act, in which architects and designers can express themselves even in already built contexts. This is also the reason why, in recent years, refurbishment methods through additional volumes have increased.

The additive approach, particularly in relation to accessibility and inclusion purposes, deserves specific mention. In this case, a high social and functional upgrade is linked to function restoring in the building: in most cases, barrier-free accessibility or inclusion systems are realised through additions to old buildings in which spaces and structural organisation preclude internal interventions: emergency stairwells, additional lifts or elevation systems, and galleries for circulation facilities are typical examples of these *functional prosthetic systems*.

The correlation between body and architecture prosthetics is not new (Wigley, 1991), and can be clarified in different functional and morphological homologies: external or internal, structural or functional, and temporary or permanent prostheses can be applied to buildings as to the human body. The concept of Exoskeleton itself, which is the main topic of this chapter, is an application of the homology between physical and functional issues of human and architectural bodies (Fig. 3.1).

FIG. 3.1 The Bionic Exoskeleton for human bio medical rehabilitation. Ekso Bionics *(Image copyright Ekso Bionics, 2011)*

The term "exoskeleton" was firstly used in the zoological science to indicate the tegument of some invertebrates with structural and chemical characteristics; in recent times, through a biomimetic approach, it has passed to the military field as a device to carry heavy loads and to biomedical practice as a technical suit for people with reduced mobility.

Referring to this correlation between body and architecture, most volumetric additions for accessibility and inclusion can be read as prosthetic devices: functional, regenerative structures that enable the building to restore its functionalities (Fig. 3.2).

FIG. 3.2 Examples of functional additions for accessibility and security: architectural prosthesis. From left: security stairwell in a historical building, Tolentini, Venice; external security stairs in New York *(Image by Lidia Savioli, 2015)*; external lift in Bolzano *(Image by Comune di Bolzano, 2014)*; external lift in the Reina Sofia Museum, Madrid *(Image by Valeria Tatano, 2014)*

As with the Exoskeleton System, functional prosthesis for accessibility can also be read as *socio-technical devices*, in which the addition of a technical apparatus allows the functional upgrade and the quality restoration of the building: a new functional programme for circulation.

However, their functionality is limited to the purely accessible, or internal flexibility improvement, whereas for the Exoskeleton, the complete and continuous morphology of the technical apparatus allows the whole reorganisation of the building structure, with improvements on many levels.

4 Rehabilitation Approaches

The adaptation for the multi-family residential typology has an additional challenge. This is due to the necessity for intervention in an inhabited environment. For this reason, key roles are played by the presence of communities, problems related to residential functions, construction site management, and the relocation of people during the implementation of the intervention.

Although the practice of demolition and new construction is possible, this "scrapping" solution (Micelli, 2011) is not always workable, firstly for social reasons, but also for economic and environmental causes. As detected by the *Guidelines for the selection and use of fuels and raw materials in the cement manufacturing process* (WBCSD, 2005), the scale of value for the management of construction waste shows that prevention, reduction, reuse, and recycle are at the top of the range of priorities (Fig. 4.1). Moreover, construction waste is not environmentally friendly, due to its impact on the eco-system. Referring, for example, to the Italian context, construction waste is recognisable as "special waste", the treatment of which requires important economic expenditure (D.M. 152/2006, *Norme in materia ambientale, Art. 184, classificazione*).

According to recent research on construction in Europe (BPIE, 2011), the general obsolescence of the building stock requests a "mending operation" (Piano, 2014): a suitable urban renewal and architectural refurbishment that must be read in the context of *integrated rehabilitation* (Montuori, 2014), a holistic approach to the redevelopment process that combines energetic, structural, social, and economic strategies in an inhabited environment.

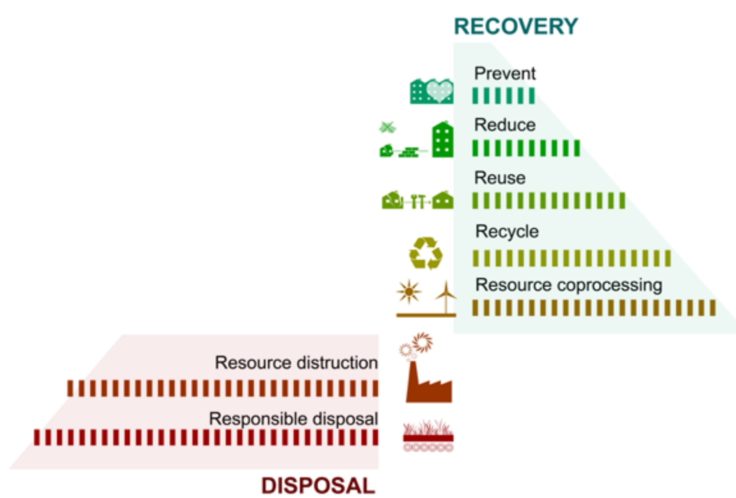

FIG. 4.1 Scale of sustainable treatment from disposal to recovery. Graphic diagram derived from WBCSD, 2005 *(Image by Francesca Guidolin, 2014)*

4.1 Functional and Social Upgrade: Strategies and Methods

As stated above, among the strategies for rehabilitation, a common method for functional upgrade can be recognised in the *additive strategy*. Several refurbishment interventions, carried out in Europe in the last two decades, have been considered and analysed, then classified throughout morphological and constructive parameters, with the aim of evaluating performances in terms of *integrated refurbishment*.

The definition of a "synoptic diagram" is based on the requirement/performance approach, and can be seen in the "taxonomy of refurbishment methods" (Fig. 4.2).

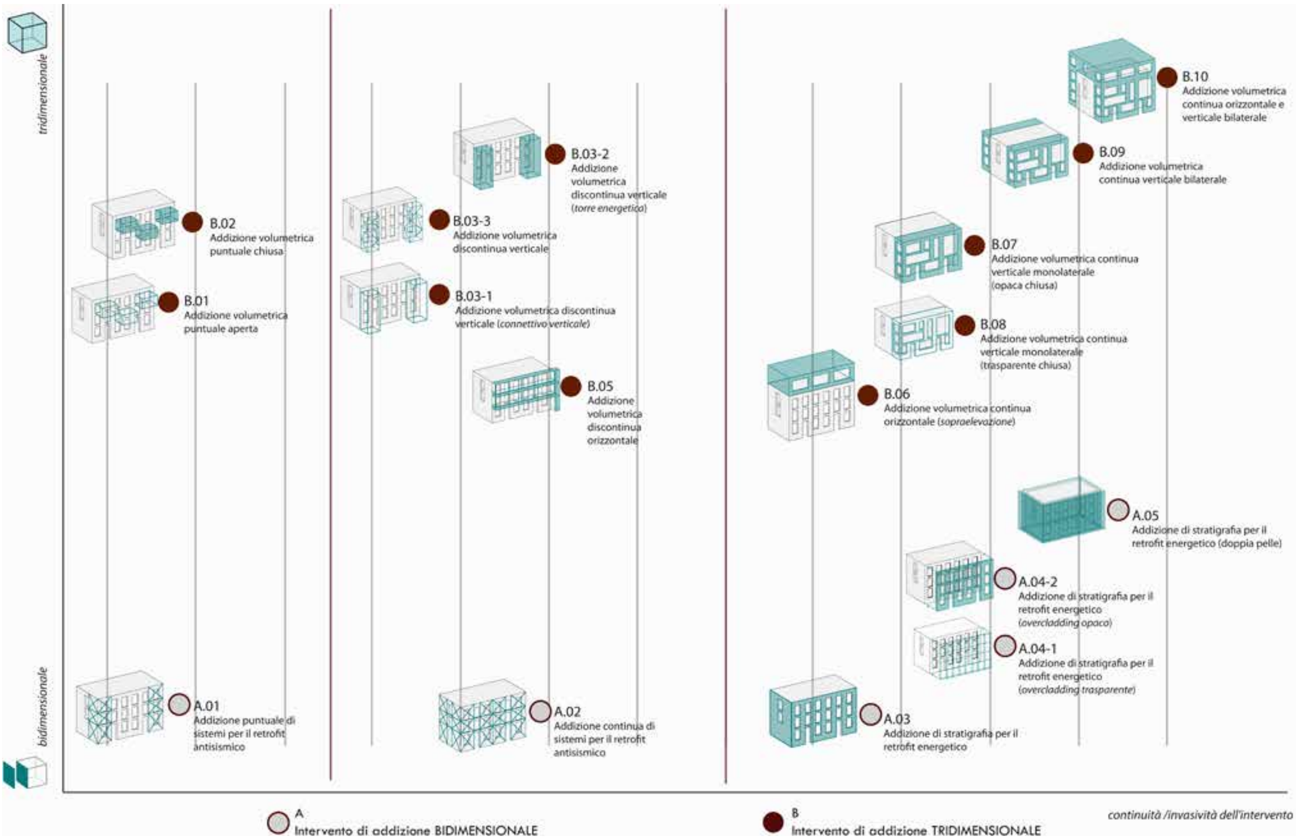

FIG. 4.2 Taxonomy of refurbishment methods, from two-dimensional to three-dimensional additive strategies *(Image by Francesca Guidolin, 2014)*

The synoptic diagram classifies on the abscissa the morphological parameters, from punctual (elements, boxes, towers) to continuous additions (both vertical, as lateral expansions, and horizontal, as roof-topping additions); whereas on the ordinate it classifies the constructive data, from two-dimensional (new high-performance layers), to three-dimensional additions (open or closed volumetric expansions).

The diagram can also be read as ranking intervention through three main types: *integration* of elements or systems; *substitution* of elements or systems with more qualitative ones; and *addition* of systems or spaces: the most relevant, as well as the most beneficial, renewal operation.

The practice of energetic and seismic rehabilitation shows the high impact of façade refurbishment: *seismic retrofit*, *overcladding*, *recladding,* and *refitting* (Trabucco & Fava, 2013; Zappa, 2011). Such integrations are added on the building envelope, or alter the envelope to create a more high-performance external shell.

The most effective solutions for functional upgrade are the additive ones, which can also improve the structure and the typological choices of buildings. Some of these actions result in punctual boxes, passive or circulation towers, and continuous and global volumes (Fig. 4.3).

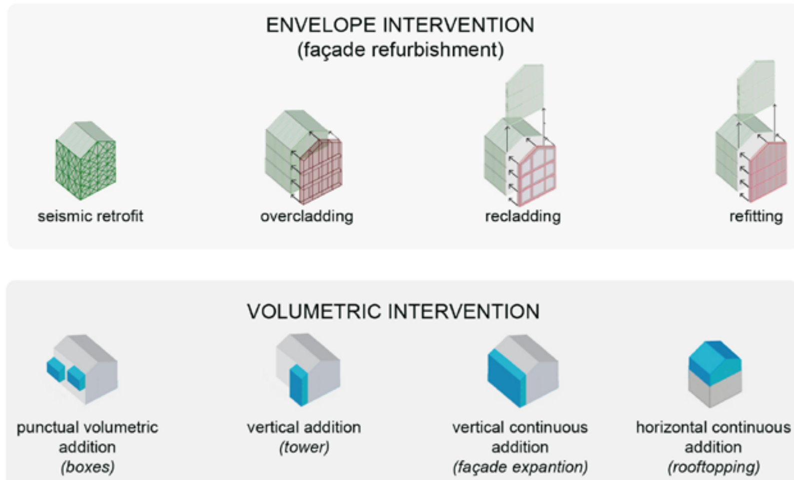

FIG. 4.3 Refurbishment methods: from façade refurbishment to volumetric additions *(Image by Francesca Guidolin, 2014)*

The results of this analysis reveal that the larger functional, energetic, and structural increase in performance lies in the area of the maximum ordinate and abscissa, where the three-dimensional construction technique intersects the volumetric addition strategies. This synoptic diagram, based on the taxonomy of rehabilitation strategies (Zambelli, 2004), finds a correlation in some European examples:

– the *Tour Bois le Prêtre* requalification by F. Druot, A. Lacaton and J.P. Vassal (Paris, 2008-2012);
– the *Villeneuve la Garenne* rehabilitation of “La Banane” by Groupe Arcane Architectes – Paris (Paris, 2009-2013);
– the *Westerpark* intervention by Van Hoogmoed Architecten (now PAN+ architectuur) (Tilburg, 2008);
– the *Leeuw Van Vlaanderen* intervention by Heren 5 Architecten (Amsterdam, 2007);
– the *Rathenow building renewal* by Klaus Sill and Jochen Keim (Rathenow, 1997);
– *Le Navi* rehabilitation by Ipostudio Architetti Firenze, a project for the European Research SuRE-Fit, 2006.

5 Towards the “Exoskeleton System”

The treatment of the envelope as a building skin can be found in recent strategies for climatic regulation, such as the introduction of shadings or skin envelope (OECD/IEA, 2013), but the possibility of integrating some volumetric additions in the envelope is an issue with high potential.

In fact, functional upgrades are realised through the addition of vertical and horizontal circulation spaces (stairs and lift, emergency exits, or emergency stairs), additional dwellings at the rooftop, private spaces inside the dwellings (additional or enlarged rooms), or collective (residential services, halls, community spaces), besides the energetic and structural improvements. Considering the more invasive intervention, that is, the global volumetric addition with a rooftop extension, it is possible to recognise the “Exoskeleton System” (Guidolin, 2016) (Fig. 5.1).Current research is investigating the adaptability potential of this device in terms of typological reshaping (Angi, 2016), as well as for its structural characteristics (Feroldi et al., 2014; Scuderi, 2015) and energetic possibilities.

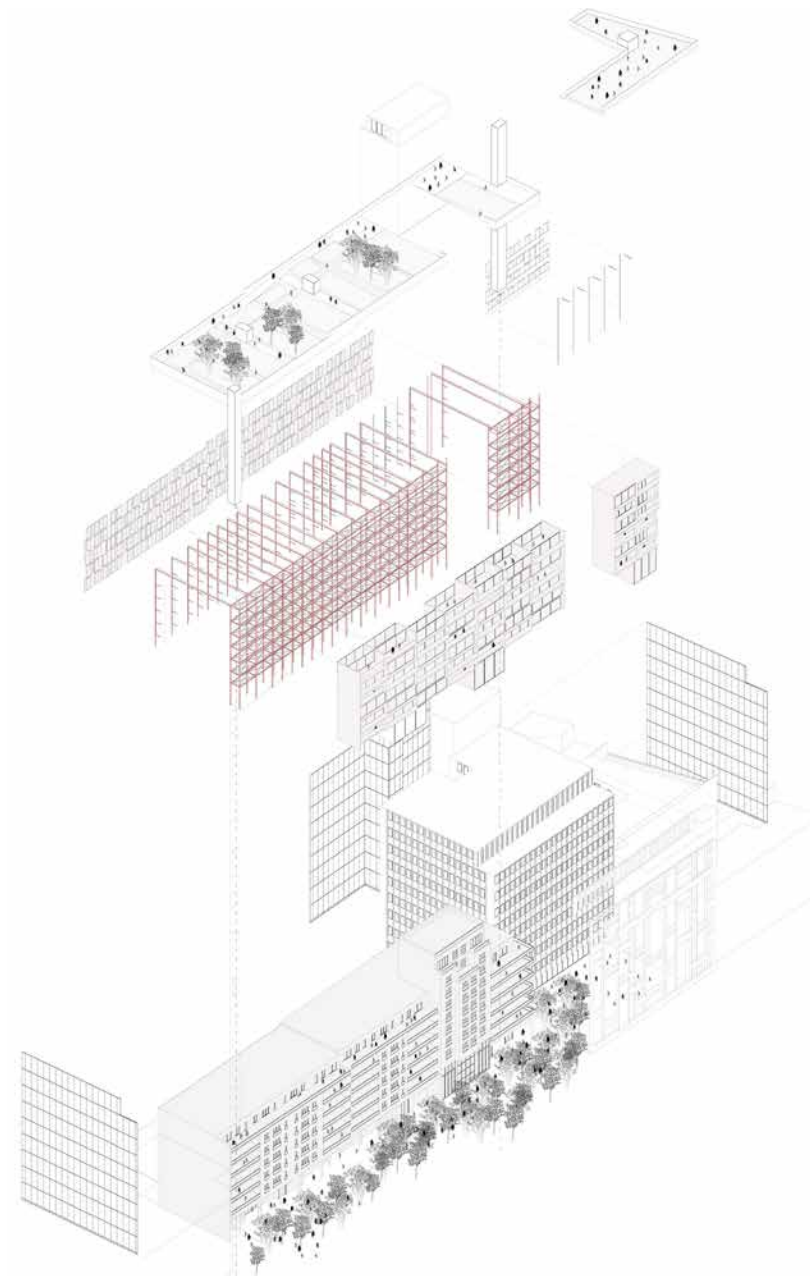

FIG. 5.1 The Exoskeleton System, image from the project "Pour une Réhabilitation Verte" *CAUE (Conseil d'Architecture Urbanisme et Environnement*) Paris International Challenge *(Image by Francesca Guidolin, Francesco Cauda, Mattia Chinellato, Francesco Messina, Enrico Robin, 2015)*

Exoskeleton structure, as can be seen in Fig. 5.2, is technologically composed of a structural system and cladding, two technological systems that can be totally designed and personalised. The standardisation of the grid with replicable modules can be customised to answer environmental and functional requirements.

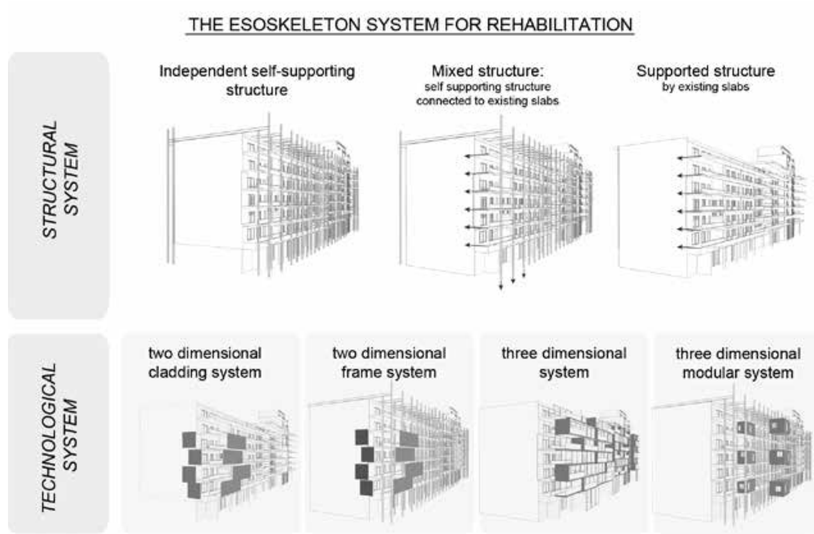

FIG. 5.2 The Exoskeleton System, structural and technological construction systems *(Image by Francesca Guidolin, 2014)*

Therefore, this additional envelope can include different private or collective spaces:

- *Winter gardens* and *greenhouses,* which, besides giving new functions, contribute to active micro-climate regulation and improvement for the dwellings, or the whole building in the case of towers. The adaptive characteristics of these new functions display their flexibility through the year, and are used seasonally and daily in different ways.
- At the same time, these spaces are used passively as buffer zones between the internal and external micro-climate, thus reducing transmittance.
- *Circulation towers*, containing stairwells, lifts, and collective spaces, that can also be used for energetic reasons such as solar chimneys, can stimulate the natural ventilation of the building, and of each dwelling if correctly designed.
- *New envelope claddings*: new windows frames are possible, by changing the old façade (which is now internal) and reconfiguring the balance between "empty and filled" space in the façade. This is achievable through a new combination of transparent or opaque cladding, realised with more insulating coatings.
- *Galleries and balconies,* which can simplify the accessibility of circulation, dwellings, and facilitate the organisation of internal space in each dwelling. In this case the building typology can be modified from a multi-level bar building to a bar building with balcony entrance. This modification enables the use of old circulation spaces as new collective spaces, or private spaces for each dwelling, or simply gives the possibility of a second fire exit for safety purposes.

The Exoskeleton System, as it relates to social characteristics, can be seen as a *socio-technical device* (Vermaas, Kroes, Van de Poel, Franssen, & Houkes, 2013). This definition was first given by Eric Trist and Ken Bamforth in 1951 (Trist & Labour, 1981) and it identifies an artefact that implies a relationship between technological issues and social ones, as well as the users' social behaviour in a place. In this respect, the use of an independent structure outside the original building is identifiable as a *socio-technical device* for four reasons:

- **Inclusion and accessibility**: being a strategy for functional upgrade in terms of accessibility could constitute a scenario for the renewal of the obsolete building stock, adapting it to ageing or disabled people, and increasing residential services and comfort.

- **Customisation, personalisation and decision-making inclusion**: a technological system allows each inhabitant to choose materials and uses: additional rooms, spaces, and technologies to improve the flexibility and adaptability of the dwellings (Reich, 1992; Wultz, 1986;).

- **Social innovation**: for multi-storey residential buildings, this is a functional issue for the activation of social participation in the development of the participative design process, from the initial phases (e.g. the mapping of needs) through to appropriate communication channels with the users.

- **Participative construction processes**: the importance of an external volumetric addition lies in the practical implications for the construction site, in particular the indirect costs of inhabitants' relocation for the management of the construction site *au milieu habité* or *en site occupé* (on a occupied site). The possibility to operate without interrupting the normal functioning of the building (e.g. avoiding the resettlement of inhabitants to other temporary dwellings) allows us to contain costs and to manage a less intrusive intervention.

These features are particularly interesting if we consider a building typology in which there is a "community" of inhabitants that has already defined its processes and rules. In such cases, the reasons that often lead to a slowdown of the refurbishment interventions result from disagreement on the inhabitants' part. Moreover, a heterogeneous social context and shared ownership (i.e. the coexistence of private and public owners) increase difficulties, highlighting different and often conflicting exigencies.

For these reasons, the establishment of programmes for public participation of communities and neighbourhoods in the decision-making processes could constitute the basis of a well-planned management structure, and for the resolution of many possible conflicts. Some recent examples apply technological devices to solve social problems during the participatory rehabilitation construction site, through the use of external structural additions such as Exoskeletons.

6 The Examples of Socio-Technical Devices for Refurbishment

The definition of a socio-technical device leads to the consideration of the Exoskeleton System as a technical artefact. In these kinds of devices, technical systems are strictly related to their social implications: it is possible to recognise a building as a closed *organisation,* in which existing rules, social relationships, and behaviours are already set up.

Thus, by introducing physical modifications to this apparatus, it is also possible to modify the pre-existing social conditions, as explained earlier (Par. 4): improving accessibility and inclusion, allowing the personalisation of technical solutions, and enabling social innovation and participation.

Recent refurbishment interventions carried out in the last decade in Europe, some of which are listed below, show how volumetric independent additions such as the Exoskeleton System can improve these qualities. Four examples from the refurbishment interventions studied in the research (Guidolin, 2017) are described here, selected for their illustrative characteristics as socio-technical devices.

6.1 « La Banane », Villeneuve la Garenne (FR)

In the "La Banane" refurbishment, realised in 2013 by Groupe Arcane Architectes – Paris, and the tenant agency *Coopération et Famille* in Villeneuve La Garenne (FR), the intervention concerned the expansion of the façades through the dismantling and substitution of claddings with the use of an external structure - a concrete exoskeleton. The construction site was not only realised "au milieu habité", but also without the need for the temporary displacement of inhabitants from their dwellings. To avoid the displacement of the dwellers, a technical solution was used in order to border the construction site for environmental and security reasons. This solution required the use of a well-suited building technology: a temporary partition was erected in each dwelling, in order to separate the construction site from the internal spaces (allowing also for asbestos removal), for a period of 3-4 weeks.

A participative process was carried out, to communicate the construction phases to the inhabitants, which included a series of meetings with the residents of the community to explain phases and results of the operation. Moreover, due to the complexity and the experimental nature of the intervention process, the construction agency, in conjunction with the architectural agency Groupe Arcane Architectes, produced some instruction manuals: a technical manual for the construction company and a communication manual for the inhabitants.

FIG. 6.1 The construction site of "La Banane" refurbishment in Villeneuve La Garenne, Groupe Arcane Architectes - Paris. *(Image by Groupe Arcane Architectes – Paris, 2013)*

This is an example of how technical tasks, if adapted and well communicated to the social players (the inhabitants) and stakeholders, can bring about the realisation of refurbishment interventions even if they are complex and difficult.

6.2 Westerpark Refurbishment in Tilburg (NL)

The refurbishment of the Westerpark neighbourhood in Tilburg, the Netherlands, in 2005, was carried out by the municipality and *TIWOS – Tilburgse Woonstichting*, with the support of the European Community in the SuRE-FIT project *(Sustainable Roof Extension Retrofit for High-Rise Social Housing in Europe*). A balance of cost-benefit ratio was carried out by Van Hoogmoed Architects (now PAN+ architectuur), demonstrating that costs related to the displacement of the inhabitants in the case of renewal can make the difference.

Three buildings were completely renovated in the Westerpark neighbourhood, by adding a floor on the rooftop and some spaces throughout the volumetric extension on the façades.The intervention was conducted simultaneously on all three buildings, forcing a substantial amount of displacement of residents (about 600,000 euros, according to the estimations of the architectural firm that conducted the intervention), which could have been reduced by dividing the operation into sections and phases (European Commission IEEA, 2010). The construction site organisation thus becomes a crucial point in managing the economy of the process, in which the inhabitant can play a non-marginal role.

FIG. 6.2 The construction site phases of the Westerpark intervention in Tilburg (NL), Van Hoogmoed Architecten (now PAN+ architectuur) *(Image by PAN+, 2005)*

6.3 Tour Bois le Prêtre (FR)

The organisation of a construction site through a participatory process was visible in the transformation of the *Tour Bois-Le-Prêtre* in Paris, by Fréderic Druot, Anne Lacaton, and Jean Philippe Vassal (2008-2012).

An architectural challenge launched by the Paris OPAC (*Office Public d'Aménagement et de Construction*) with the architect François Helene Jourda, did not allow this refurbishment as part of it, although some design characteristics had already been established. The challenge also excluded the demolition of the tower; in addition, the challenge requested the participation of dwellers in the definition of programmes from the beginning of the operation. Dwellers were also involved in the challenge programme, through a study of their requirements and needs (security, collective spaces renewal, new uses).

FIG. 6.3 The Tour Bois-le-Prêtre transformation, Frédéric Druot, Anne Lacaton, Jean-Philippe Vassal *(Images by Matteo Busa, 2014)*

The process started with the mapping of exigencies and the functional requirements for each residential unit. As in the *Villeneuve La Garenne* intervention, a single dwelling was first renovated to be used as a mock-up example for inhabitants. This action led the dwellers to understand what kind of intervention was going to take place, the construction site process, and the operations. According to Frédéric Druot, the construction site director was required to be present on site 60% of the time; moreover, a professional who took charge of relations with the inhabitants 100% of the time, during the construction stage carried out "au milieu habité" (PUCA, 2012).

In this case, an important improvement for accessibility was carried out thanks to volumetric additions: the existing stairwells and lifts were substituted with two transparent lifts, located at the north and south façades, with transparent materials, which allow the natural lighting of the halls of every floor. Also, fire security compartmentations were added, one for each floor, made up of transparent material too, for the same reason.

These examples show how the refurbishment device of the Exoskeleton System can be recognised as an application of a *socio-technical system* due to its ability to integrate purely technical and material aspects with social issues that this constructive device provides, not only in terms of functional upgrade (i.e. flexibility, adaptability and personalisation), but also in the feasibility of the intervention process, such as in the construction site management.The Exoskeleton System can avoid the interruption of indoor activities, thus being useful in cases in which the intervention process is inhibited by social reasons (for instance in hospitals, social housing, and multi-storey and heterogeneous property buildings).

In rehabilitation interventions, the possibility of avoiding inhabitant relocation is achievable through the introduction of rooftop extensions, which can be used as temporary dwellings for the users whose dwellings are being retrofitted. The rooftop expansion, which can be read as a *continuous horizontal addition* is possible due to the structural independence of the Exoskeleton System, which has independent foundations.

One of the justifications of this practice is the feasibility study carried out by Anna Delera and Paolo Carli (Polytechnic University of Milan) for the Quartiere Barzoni intervention, in which inhabitants are to be moved towards a new temporary construction during the intervention (Carli, 2012). In this feasibility study, there were three phases:

- The first phase, with the mobility inside of the four dwellings and external mobility of nine others;
- The second phase, with the internal mobility of fourteen dwellers in temporary rooftop houses, and six dwellers in external mobility;
- The third phase, with eighteen new dwellings on the rooftop and seven dwellers in external mobility.

The result was the construction of two towers in the north sector, the rooftop addition to other bars in the southern sectors with the relocation of as few dwellers as possible.

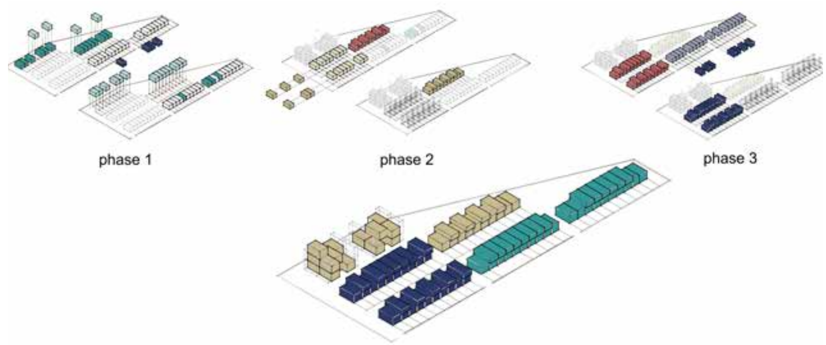

FIG. 6.4 The construction site planned for the feasibility study for Quartiere Barzoni, Milan. Anna Delera and Paolo Carli (2012) *(Image by Francesca Guidolin, 2015)*

7 Conclusion

The contemporary scenario for multi-storey residential buildings is complex from different points of view. The loss of quality, in terms of energy and structure, leads to deep retrofit interventions, whereas functional and architectonic obsolescence asks for a new building organisation and appearance, and in most cases, also a new envelope for the building. These exigencies are often typical of areas in which the social situation is complex, for example, in multi-storey residential buildings of the '50s-'70s that are sometimes characterised by decay or weak neighbourhood areas.

The analysis undertaken classifies some strategies for rehabilitation in the perspective of upgrading the structural, energetic, and functional performances, and overcoming problems that multi-storey residential buildings can carry.

As the "broken window theory" (Wilson & Kelling, 1982) states, social degradation is deeply linked to material decay. This fact brings us to consider the importance of applying a "technological reconnection" (Angelucci, Cellucci, Di Sivo & Ladiana, 2015) in the refurbishment intervention, conceiving an adaptable solution for all aspects, in a holistic way.

The Exoskeleton System could be considered among the various volumetric addition strategies, for its potential to become an "integrated requalification" practice for buildings dating from the period after the second world war. Beyond the energy and structural necessities, which it is able to satisfy, the Exoskeleton System focuses on functional performances through the analysis of the space inclusiveness quality, in order to achieve an architectural upgrade of buildings and solve consequent circulation issues.

In the case of the structural seismic refurbishment in particular, it allows us to bear and to discharge horizontal seismic thrusts to the vertical structures, implementing the resilience of the building through dumper systems. On the other hand, for energetic purposes, it is an adaptive double envelope, able to regulate energy flows from internal environmental conditions to external ones and vice versa. The possibility of expanding volumes leads to its consideration as an *architectural functional prosthesis*, in which new structures afford the empowerment of quality in use: lifts, additional rooms, new flexible private or collective spaces fulfil the requirements of the contemporary way of "living".

Besides those potentialities, however, there are some relevant limits for its application. They can be summarised as *urban-planning constraints*, due to the need for external free space, which defines the building expansion, and *dimensional and spatial constraints,* which ask for an appropriate design in order to respect distances and maximum heights in the urban context.

Alongside those limits, others are *economic and administrative*: sometimes mixed ownership buildings, in which private and public dwellings coexist, are more difficult to renew due to the financial effort of this kind of structure. In this case, a refurbishment intervention purely to the façade is more simple to apply, even if it doesn't bring any functional or social improvement.

The analysed interventions show the high potentiality of volumetric additional methods. In such operations, the technological issues are related to some social benefits, which have to be considered as equally important in the new scenarios of adaptive retrofit. This quality, in fact, is necessarily declined throughout the social impact that buildings have in their life-cycle assessment, for the urban fabric but also for the communities - the social organisations - they contain.

If we read the community of inhabitants as a pre-existing closed organisation, with its own processes, social and relational structures, people and programmes, it is clear that every spatial and technical modification of this *habitat* needs to be the most flexible possible and custom-designed for the specific context.

Read as a socio-technical device, the Exoskeleton is a technological strategy identifiable as an adaptable method for future uses, from the perspective of resilience and adaptability of the already built context.

At an urban scale, it is possible to introduce the Exoskeleton as a strategic issue for the regeneration of communities: new community services, spaces for aggregation and public or collective activities. In addition, the density increase can be seen as an opportunity to develop mixed use zones.

These results, if combined with the European demographic future projection of ageing and the need for flexibility, can determine more sustainable living conditions for communities. Moreover, at the scale of the building, the architectural appearance and performance can be completely modified through the re-design of an adaptive envelope. A new skin for the building, which is able to manage and regulate the energetic flows, creates new spaces for different and sustainable uses such as winter gardens, greenhouses, and new mixed-use rooms and spaces.

The Exoskeleton System can thus be seen as a part of strategic intervention for neighbourhood regeneration: the future perspective of rapid demographic, social, and energetic modifications requires self-adapting, flexible, and resilient buildings.

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