UNIVERSITY OF TRENTO
DEPARTMENT OF CIVIL, ENVIRONMENTAL
AND MECHANICAL ENGINEERING

DOCTORAL SCHOOL IN ENGINEERING OF
CIVIL AND MECHANICAL STRUCTURAL SYSTEMS
XXVIII CYCLE

ADAPTIVE EXOSKELETON FOR THE INTEGRATED RETROFIT OF SOCIAL HOUSING BUILDINGS

Author:
Giuliana SCUDERI

Supervisor:
Prof. Enzo SIVIERO

February 2016

University of Trento
University of Brescia
University of Bergamo
University of Padova
University of Trieste
University of Udine
University IUAV of Venezia

UNIVERSITY OF TRENTO
Doctoral School in Engineering of Civil and Mechanical Structural Systems
XXVIII cycle

Head of the Doctoral School:
Prof. Davide Bigoni, University of Trento (Italy)

Final examination: 04/04/2016

Board of Examiners:
Prof. Elisabeth Vintzileou, National Technical University of Athens, Greece.
Prof. Daniele Vignoli, University of Florence, Italy.
Prof. Hervé Degée, Hasselt University, Belgium.
Prof. Claudia Battaino, University of Trento, Italy.

SUMMARY

This doctoral thesis presents technical strategies for the rational maintenance of the building heritage directed at the integrated retrofit of social housing stocks.
The study comprised the analysis of recovered residential buildings in order to develop new sceneries to adopt in critical situations, leading to the definition of a new experimental practice called “adaptive exoskeleton”.
This strategy involves the wrapping of the entire original building with a three-dimensional structural envelope, the exoskeleton, using a construction process able to limit interferences on the use of the building and on the life of its inhabitants. The exoskeleton is an independent frame, carefully designed at the joint-scale to achieve awareness of the constructive sequence and of the optimization of the resources.
Dry construction technologies resulted to be the most effective, because based on the principles of lightness and reversibility, and because they allow to realize a structural grid able to satisfy different standards in relation to the changing user conditions.
The strategy of the adaptive exoskeleton, which exploits optimized and industrialized components, appears convenient in relation to large-scale interventions on the built heritage and, at the same time, it is architectonically versatile, with many possible options adaptable to different cultural contexts.
The structural frame can be adjusted to different dimensions, extensions, typologies and technologies, maintaining the same basic characteristics.
Passive dissipative devices realized with shape memory alloys, strategically located as connectors with the existing building, are used in order to reduce the lateral displacements during earthquakes.
A key idea is the separation between the long lasting elements of the construction, such as the structural systems, and the parts that can be updated progressively in relation to the requirements of the user or to the technological innovations. This principle is convenient in large-scale campaigns, where it is necessary to create a solid base structure without renouncing to the individualization and the variety of the demand, which stimulates the introduction of architectural components with a shorter use-life.
The structural characteristics of this construction and its ability to dissipate the seismic input, were analysed during a research period of twelve months undertaken at the Eindhoven University of Technology (Netherlands) at the unit of Innovative Structural Design of the Built environment department.
The verification phase considered two building typologies, due to their high diffusion in Europe: the use of the finite element software SAP2000 required the application of a “frame model” for masonry buildings and of a “strut model” for the concrete frame with masonry infill.
The seismic behaviour of the buildings was analysed before any intervention and after the introduction of the adaptive exoskeleton implemented with shape memory alloys-based devices.
The experimental phase was also undertaken with reference to San Bartolomeo estate in Brescia, Italy.
Summarizing, the research underlined the convenience of applying retrofit processes in opposition with demolitions and reconstructions, above all in terms of social and environmental costs.
The adaptive exoskeleton, in particular, provides an integrated and synergic solution because while improving the seismic behaviour of the structure, offers additional space for services and functions, increasing the economic value of the building and improving its energy performances and its architectural characteristics.

SOMMARIO

La presente tesi di dottorato presenta strategie tecniche per la manutenzione razionale del costruito dirette al retrofit integrato dell'edilizia sociale.
Lo studio ha richiesto l'analisi di progetti di recupero dell'edilizia residenziale al fine di sviluppare nuovi scenari da adottare in situazioni critiche, portando alla definizione del cosiddetto "esoscheletro adattivo".
Secondo questa strategia l'edificio esistente viene avvolto da un involucro strutturale tridimensionale, l'esoscheletro appunto, usando processi costruttivi in grado di limitare interferenze sulla operabilità dell'edificio e sulla vita dei suoi abitanti. L'esoscheletro si presenta come uno scheletro indipendente, progettato con attenzione fino alla scala del nodo al fine di acquisire consapevolezza riguardo al processo costruttivo e all'ottimizzazione delle risorse.
Le tecnologie a secco sono risultate le più efficaci, perché basate sui principi della leggerezza e della reversibilità e perché permettono di realizzare una griglia strutturali capace di soddisfare i differenti standard a fronte di cambiamenti dell'utenza.
Questa strategia, che sfrutta componenti ottimizzati e industrializzati, è conveniente in relazione ad interventi su larga scala applicati al patrimonio costruito e, allo stesso tempo, è architettonicamente versatile, con molte opzioni possibili adattabili ai diversi contesti culturali.
Lo scheletro strutturale può essere modificato in dimensione, estensione, tipologia e tecnologia, mantenendo le stesse caratteristiche di base.
Dispositivi di dissipazione passiva realizzati con metalli a memoria di forma, posizionati strategicamente come connettori con la struttura originaria, sono usati per ridurre gli spostamenti orizzontali duranti i terremoti.
Un' idea chiave è la separazione tra gli elementi duraturi della costruzione, come il sistema strutturale, e le parti che possono essere aggiornate progressivamente in relazione alle necessità dell'utenza o alle innovazioni tecnologiche occorse. Questo principio è conveniente nelle campagne su larga scala, dove è necessario creare una struttura di base solida senza rinunciare all'individualità e alla varietà della domanda, che stimola l'introduzione di componenti architettoniche con una vita d'uso più breve.
Le caratteristiche strutturali di questa costruzione e la sua capacità di dissipare gli input sismici sono stati analizzati durante un periodo di ricerca di dodici mesi presso l'Università tecnica di Eindhoven (Paesi Bassi) sotto l'unità di Design Strutturale innovativo del Dipartimento dell'ambiente costruito.
La fase di verifica ha considerato due tipologie strutturali largamente diffuse in Europa: l'uso del software per l'analisi a elementi finiti SAP2000 ha richiesto l'utilizzo del "modello a telaio" per le strutture in muratura e del "modello a puntone" per le strutture in muratura confinata.
Il comportamento sismico degli edifici è stato valutato prima e dopo l'introduzione dell'esoscheletro con i dispositivi di dissipazione con metalli a memoria di forma.
La fase sperimentale è stata anche svolta in relazione al quartiere San Bartolomeo a Brescia, Italia.
In conclusione, la ricerca ha sottolineato la convenienza dei processi di retrofit rispetto alle demolizioni e ricostruzioni, soprattutto in termini di costi sociali ed ambientali.
Lo scheletro adattivo in particolare offre una soluzione integrata e sinergica poiché, mentre migliora il comportamento sismico della struttura, offre anche spazio addizionale per servizi e funzioni, aumentando il valore economico dell'edificio e migliorandone le performance energetiche e le caratteristiche architettoniche.

CONTENTS

1. THE RESEARCH PROJECT

1.1 Introduction

In Europe the residential stock accounts for the 75% of the total number of buildings, with a significant share built after the Second World War, when most of the countries experienced housing shortage due to war devastation, population increase and economic growth.
The necessity to produce a large amount of affordable dwellings required a shift away from traditional construction methods towards fast and industrialized processes. The layout of the estates was also revolutionary, with large building blocks surrounded by green open fields, result of the influences operated by pre-war Modernists, such as Le Corbusier in France and Walter Gropius in Germany.
After the oil crisis of the 1970s and again in the 1980s, relevant architectural, functional and structural problems manifested for the first time and since then regeneration programmes tried to improve the quality of these estates, at the same time regaining their popularity, progressively lost because of the inability to respond to the needs of a new society.
Recently many cities in Europe are encouraging the recovery of the existing building heritage, rather than replacing them with new constructions, since life extension of the existing housing stock is seen more convenient for many reasons. The cost of the conversion is usually lower due to the presence of pre-existing elements and, since the process takes around half of the construction time necessary for demolition and reconstruction of the same floor areas, the financing, the effects of inflation and the risk of collateral events and related expenses are reduced. The money invested in retrofit can be capitalized in relatively short time, considering the increase in value of the construction, the reduced energy and water consumption and the new environmental quality achieved.
To maximize the benefits a multi-purpose campaign of architectural, functional and structural retrofit is essential. On the other hand, the complexity of the issue requires integrated and innovative solutions. In the field of social housing, in particular, there is the necessity to develop models more prone to answer to the new way of living of a dynamic society and to reproduce the pattern of the changing city.
The selection of the most suitable strategy depends on several factors, such as the structural typology and technology of the buildings, its historical and functional importance, and the socio-economic issues connected with the presence of serious damages and obsolescence.
Typically, the ratio between the costs and the performances achieved is determinant for the definition of the appropriate retrofit program: synergetic operations should improve the overall characteristics of the buildings, at the same time reducing the ancillary construction expenses.
The interpretation of the state of the art in the field of residential renovation was fundamental to understand how countries and designers have faced the issue, and it moves from the analysis of European projects realized in the last decades. These episodes have been selected as “best practices” to illustrate the most convincing and successful solutions embraced by the different countries.
The study highlighted the leading role of the envelope, a liminal space between inside and outside, able to determinate and modify climate control, energy performances, aesthetical values and architectural characteristics of the building, influencing also its structural response.

Envelope directed interventions could have immediate effect also on the surroundings, defining neighbourhoods that are more attractive and interrupting the monotony that often characterises post Second World War social housing estates.
These experiences also showed a significant correlation between the selection of a construction technique and the results accomplished, so that most of the successful renovation projects rely on approaches that allow simple future interventions, in strong opposition with traditional methods, which need specialised skills for any update.
This degree of reversibility and flexibility can be obtained using simple and robust dry-construction technologies, with reduced time and costs for the intervention and lower environmental impacts during the useful life of the building organism and at its end, thanks to the high percentage of recovery of the mechanically assembled components.
A key idea is the separation between long lasting elements of the construction, such as the structural systems, and parts that can be progressively updated in relation to the requirements of the user or to the technological innovations.
This principle is convenient in large-scale campaigns of intervention, where a solid base structure is fundamental but without renouncing to the individualization and the variety of the supply, stimulated by the introduction of architectural components with shorter use-life.
The research unit at the Department of Civil, Architectural and Environmental Engineering and Mathematics (DICATAM) at the University of Brescia has undertaken experiments in this direction, promoting an "integrated" system called the "adaptive exoskeletons" capable to update, technologically and typologically, the architectural objects thanks to standardised and interchangeable technologies and building systems.
In biology, the exoskeleton is an external, light and resistant armour connected with other apparatuses and able to protect the internal areas of a body from external input, such as excessive sunlight and temperature or impacts and attacks. In this way, the exoskeleton performs a very complex set of roles from the structural to the thermal, from the aesthetical to the functional, being also able to adjust over the time in order to respond to the growth of the insects.
At the same way, the "adaptive exoskeleton" is imagined as an enclosing cage, dry-assembled frame wrapping the existing building, which can be preserved and enhanced in terms of performance, safe and safety, seismic behaviour and aesthetic quality.
The new structural element can be filled with individual and independent industrialized components, new services and functions that can be used to change to morphology of the single apartment or to create new accessibility patterns. These components can be substituted progressively to be updated to the newer technologies or to respond to the changed needs of the users, providing an adaptive and flexible behaviour.
The structural characteristics of this construction and its ability to dissipate the seismic input were analysed during a research period of twelve months undertaken at the Eindhoven University of Technology (Netherlands) at the unit of Innovative Structural Design of the Built environment department.
The final configuration considers the location of passive dissipative dampers at the interface between the existing building and the new structural envelope, in a convenient position for the assemblage, the monitoring, the maintenance and the substitution of components.
Shape memory alloys (SMA) were selected to design the damping unit because of their intrinsic properties – recentring and energy dissipation capabilities, excellent corrosion and fatigue resistance, large elastic strain capacity, hysteretic damping – with great potential in structural retrofit.
Among these alloys, Nickel-Titanium (NiTi) are the best candidates for these passive control devices, owing to their superelasticy, the low sensitivity to temperature, and the higher resistance to corrosion and fatigue.
With respect to the traditional retrofit methods, the construction of the "exoskeleton" does not interfere with the functionality of the buildings, reducing all the indirect costs; additionally, maintenance, inspection and substitution of the dampers result simpler due to their concentrated localization.

The adaptive exoskeleton provides an integrated and synergic solution: the three-dimensional structural envelope, while improving the seismic behaviour of the structure, offers additional space for services and functions, increasing the economic value of the building and improving its energy performances and its architectural characteristics.
The verification phase considered two building typologies due to their high diffusion in Europe: the use of the finite element software SAP2000 required the application of a “frame model” for masonry buildings and of a “strut model” for the concrete frame with masonry infill.
The seismic behaviour of the buildings was analysed before any intervention and after the introduction of the “adaptive exoskeleton”, a steel frame with parietal cross braces connected to the existing building with SMADs.
It was necessary to perform nonlinear analyses, which considered three different areas - zone 1, 2 and 3 - within the Italian territory characterized by different levels of seismicity: zone 1 corresponds to Brescia (Brescia), zone 2 to Borgo Tossignano (Bologna) and zone 3 to Aielli (L’Aquila).
Finally, the strategy was verified for a real case study, a building located in the city of Brescia, in San Bartolomeo neighbourhood, characterized by an irregular concrete frame with brick infill, modelled in the software SAP2000 with an “equivalent strut model”.
Both in the theoretical cases and in the real case study the “adaptive exoskeleton” with NiTi based SMADs gave promising results and showed to be effective in reducing the lateral displacements and interstory drift values, at the same time owing the capability of recentring the building after the removal of the input loads.
Yet, despite the consistent potential of SMAs, their use is still limited in civil engineering structures because of their high cost per unit weight.
The research then collected the relevant literature material, from which it appears that the use of SMA-based passive control systems, in spite of the better overall performances, does not imply higher costs, and in any case not higher than those of current passive control systems, such as the common dissipating steel-based braces.
Also, a decrease in the cost of the material can be produced by an increased demand, so it is expected that the price will continue to decrease as soon as applications are developed in the field of civil engineering, such as the retrofit programme presented in this thesis.
To conclude, the increase in the value of the building after the retrofit is believed to equalize the costs of the interventions, thanks to the new energy performances but also to the new available spaces and services.

1.2 Scope and relevance

The research proposal belongs to the wider topic of urban regeneration, connected also with the recovery, reuse and conversion of the existing building stock.
The European Union and the single authorities have launched pilot research projects to assess the future urban development of European cities, achieving comparable results despite the different initial conditions.
The author will refer principally to three research projects, which have constituted a fundamental starting point for the conception of the final design strategy.

SuRE-FIT (2007 – 2009)
Rooftop expansions has been proven as a feasible solution for achieving efficient retrofit in social housing, combining energy-saving measures with social, ecological and economic advantages.
The new extensions are industrialized and flexible, technologically and financially efficient, and they can allocate new dwellings or they can provide additional space for the existing ones.

The energy losses are radically reduced, while the heating and ventilation systems can be substantially improved. The strategy reduces also the use of material by reusing the existing constructions and extending their lifespan.
Thanks to the financial surplus resulting from a better use of the land with its existing facilities, housing companies and local authorities can solve the major problem of the financing of retrofit programmes.

Paris Plus petit (2008 – 2009)
The project by MVRDV is one of ten proposals envisioned for the future of Paris.
The idea aims at increasing the density, the efficiency and the ecology of the city thanks to a strong combination of awareness and development.
The first step is the creation of a plan of strategies for the city to meet the future needs of the society, based on the promotion of seventeen "well-planned" interventions. The programme promotes also the construction of new pleasant housing areas within green surroundings, thanks to the space made available by the creation of a buried and highly efficient infrastructural network.
Efficient transport, quality of environment, culture and social cohesion are the results of interventions intended to transform Paris into a compact and sustainable city.

TES Energy Façade (2008 – 2010)
TES Energy Façade is a proposal directed at improving the energy performances of the building heritage produced in Europe between the 1950s and 1980s, requiring today of major retrofit interventions.
The method focuses on the modification of the energy characteristics of the envelopes of the constructions, applying a timber based system conceived following a cradle-to-cradle principle.
The improvement originates benefits in terms of energy savings and for the reduction of detrimental emissions caused by the residential stock.
Since every activity in a construction process is responsible for environmental impacts, in terms of consumption of resources and energy and production of waste materials, a possible solution is the use of biological and natural timber-based materials, which can burn and regrow.

The previously mentioned research projects deal with important themes connected with the renovation of the built environment, providing a panorama of the topics addressed by current researches in European context (Table 1.1).

<table>
<tr><th>TES Energy Façade</th><th>SuRE-FIT</th><th>Paris Plus petit</th></tr>
<tr><td colspan="3">ECOLOGY AND GOOD ENVIRONMENT</td></tr>
<tr><td colspan="2">SUSTAINABLE RETROFIT AND PROLONGED LIFESPAN</td><td></td></tr>
<tr><td></td><td colspan="2">DENSITY AND COMPACTNESS</td></tr>
<tr><td colspan="3">ENERGY EFFICIENCY AND REDUCED EMISSIONS</td></tr>
<tr><td></td><td colspan="2">FINANCIAL SURPLUS AND NEW PROVISIONS</td></tr>
</table>

Table 1.1
Comparison between the themes addressed by the three research projects.

Despite the many retrofit projects recently developed by European countries, still few studies have been directed at improving structural characteristics of buildings and at promoting campaign of structural rehabilitation.
The present thesis adds to the current knowledge new considerations regarding the reduced structural vulnerability of the existing heritage, by suggesting a retrofit programme that is corrective and at the same time preventive.
The new strategy promotes also a new financial value for integrated retrofit, enhancing the marketability of the building by improving its performances.
The innovation of this approach relies on the long-term span of the proposal, which recognises the diversity of each project and context, as well as a space for individuality for both users and designers, in contrast to existing campaigns, mostly providing static and rigid solutions.
Refurbishment of social housing estates is a sensitive topic for our community, since it is expected to have a big impact on the society and on the environment.
Physical decay of social housing estate often results in problematic social environment, with difficult living conditions and detrimental landscapes: higher income groups then leave the estates, being replaced by weaker groups with less economic capacities to maintain the estate.
Integrated retrofit programmes can reverse this loop, providing an attractive environment and regaining the lost popularity of these estates.
On the other hand, a fast changing and developing society requires today new living criteria, with spaces able to adapt to its dynamism on a long-term vision, undermining the consistency of the traditional dwelling morphology.
New models need to be developed in order to respond to the developing requirements of our communities and markets.

1.3 Research questions and thematic packages

Proved the convenience of retrofit processes in opposition with demolitions and reconstructions, the aim of the thesis is presenting technical strategies for the rational maintenance of the building heritage with low social and environmental impacts.
New design practices for the requalification of “suffering” neighbourhood are developed with limited costs, using appropriate technologies to satisfy different target users and to improve the performances and the quality of the spaces.
The key idea of this research is that substantial and durable improvements can be achieved only considering the complex dimension of the problem, suggesting and integrated and holistic intervention.
With this awareness, the author formulates the following three research questions.

Q1: Which integrated approach of building retrofit could solve within the same intervention the complex and delicate conditions of social housing stock?

Q2: Which strategies allow a long-term use, in terms of life cycle extension of the constructions but also in relation of the changing needs and requirements of a dynamic society?

Q3: Which is the role of the newer technologies and techniques in defining new sceneries for social housing retrofit?

Six thematic packages constitutes the frame within which it was possible to find the answers to the three questions (Table 1.2).

THEMATIC PACKAGES	FIELDS	TOPICS	CHAPTERS
T1	Structure	– Dry construction technologies – Framed structures – Smart materials and shape memory alloys – Seismic vulnerability – Structural retrofit, damping systems – Dynamic and static nonlinear analyses	2, 3, 4, 6, 7, 8, 9
T2	Architecture	– Obsolescence – Flexibility and adaptability – Social housing – Urban forms	2, 3, 4, 5, 7, 9
T3	Society	– Social housing – Co-housing – Self-construction – Adaptive and flexible dwellings – Social cohesion and security	4, 5, 2, 9
T4	Function	– Accessibility – Mixed use – Mixed target – Service provision	4, 5, 7, 9
T5	Technology	– Materials – Energy performances – Emissions – Customization	4, 6, 7, 9
T6	Construction	– Industrialization – Life cycle expansion – Dry construction technologies – Remanufacturing – Design in obsolescence	3, 4, 6, 7, 9

Table 1.2
An overview of the six thematic packages addressed by this thesis.

1.4 Research methodology

The research have been conducted following three stages, with five principal activities (Table 1.3).
Part of the research has been undertaken at the Eindhoven University of Technology in the Netherlands, at the Department of the built environment with the unit of Innovative Structural Design.

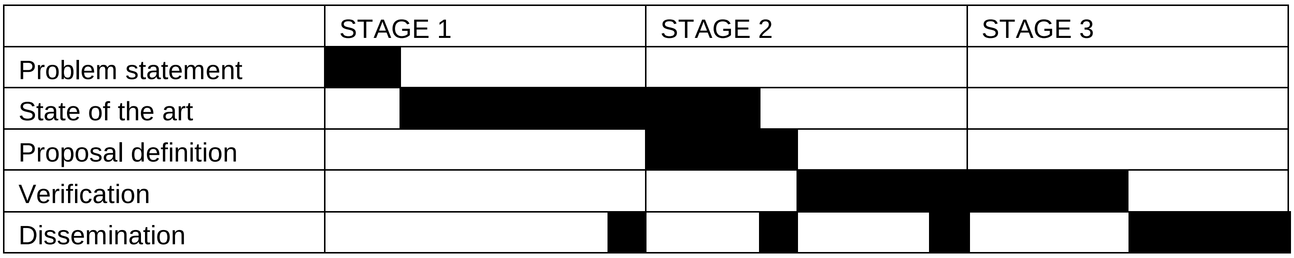


Table 1.3
Interrelation of project steps.

STAGE 1.
The first stage of the project corresponded to the definition of the problem and to the extensive analysis of the state of the art in the field of residential renovation and envelope-directed strategies.

The results of the study can be found in 3 papers (1 double-peer reviewed journal paper; 1 national conference paper; 1 international conference paper).

STAGE 2.

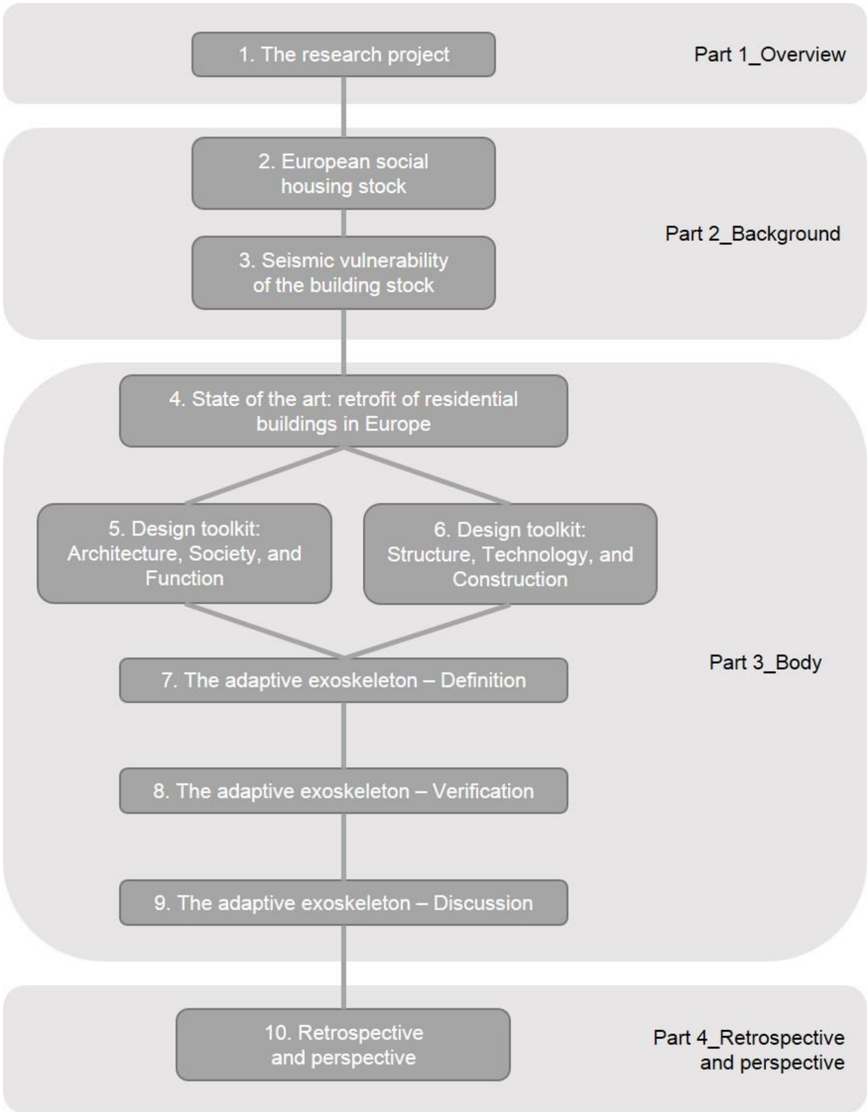
The second stage corresponded to the analysis of the data collected in the first stage and the consequent definition of a proposal. The verification of the strategy adopted was carried out at the Eindhoven University of technology (Netherlands) with the Innovative Structural Design Unit.

The results of this phase were presented in 3 papers (1 double-peer reviewed journal paper; 1 international conference paper; 1 international conference poster).

STAGE 3.

The verification of the proposal, the discussion, conclusions and the definition of possible further developments were undertaken in the third stage of the research. The results of the analysis will be formally presented in the PhD thesis, which have been developed in the second half of this stage.

1.4 Outline



2. EUROPEAN SOCIAL HOUSING STOCK

2.1 Introduction

The market of recovery appears today as the only horizon for a building sector in continuous decrease.
In recent years, the annual growth rates of the residential stock encountered only the 1%, reflecting the impact of the widespread economic crisis.
In relation to the issues connected to the energy consumption and pollution issues, new constructions represent today such a small percentage of the built heritage to be almost irrelevant (Jaretti, 2008).
The Buildings Performance Institute Europe evaluated that the largest energy saving potential is associated with the older buildings, considering that in some cases buildings constructed from the 1960s are worse than the ones of the earlier decades (2011).
In Europe a significant share of this stock is older than 50 years, with around 40% of buildings constructed before the 1960s when regulations in the field of energy and safety were limited.
Other problems are connected with the technical, structural and architectural obsolescence of the residential stock and of the surrounding areas, so that the theme of urban regeneration recently became popular, spanning from redevelopments at a urban or territorial scale to localized small-scale episodes of "urban acupuncture" (Lerner, 2014). Both these experiences show the innovative attitude of European countries in promoting pilot projects and new strategies.
This research focuses on the building stock produced after the Second World War, when Europe registered an extraordinary emergence of residential districts, built in order to respond to the increasing demand for social housing due also to the massive destruction caused by the conflict (Turkington et al., 2004).
Today about 41 million people live in these estates in Western Europe, where they are becoming the main target of urban policies. They consist of high-rise, low-rise and single family dwellings, sometimes owner-occupied and more often rented or low-rented.
The layout of these estates was at that time revolutionary: large building blocks and large open fields between the blocks, with the emergence of new urban landscapes (Murie et al., 2003).
The market and the public accepted positively this new housing estate (Murie et al., 2003) but the critical economic and social conditions required fast construction processes and simplistic technologies to provide housing at affordable prices in short time.
In many countries, the construction industry was also seen as a possibility to grant new job places for unskilled labour (Di Biagi, 2001).
The oil crisis in the 1970s pointed out the inadequate performances of these estates, introducing for the first time the themes of thermal insulation and energy efficiency. Again, from the 1980s, relevant architectural, functional and structural problems manifested for the first time and the estates, once attractive, lost progressively their popularity and started their decay process (Power, 1997; Andersen, 2003; Murie et al., 2003).
The first political policies concentrated on the demolition of social housing estates as well as on realizing new buildings elsewhere (Priemus, 1989), but since the 1990s the attention shifted mostly towards interventions of recovery.

This chapter will describe Post Second World War social housing sector in Europe, and in the Italian context in particular, presenting the principal characteristics of the stock, and the mechanisms connected to obsolescence and decay.
Consequently, the theme of building renovation will be introduced and analysed in contraposition to building replacement.

2.2 Social housing in Europe: development and decay

After the Second World War, a large housing shortage and the necessity of economic processes required the development of new construction methods (Andeweg et al., 2007), with the predominance of industrialised techniques, in origin promoted by the Modern movement (Moe & Smith, 2012), generally known as non–traditional construction technologies.
These prefabricated systems involved lower costs than traditional ones, and became very common in many central, east and north European countries.
Already in the first years of their diffusion, their implementation was supported by a great amount of real applications, because the same scheme was reproduced almost identically in different social housing estates throughout each country.
In the eastern part of Europe, as well as in Sweden and Denmark, the prevailing technology was based on large panels, while in France and in the Netherlands experienced a wider variety of techniques, including some more experimental made of stacked concrete.
On the contrary, industrialised prefabricated systems were not particularly diffused in southern Europe, where the stone and brick tradition was deeply rooted (Andeweg et al., 2007).
In the same period, new housing policies were developed (Andeweg et al., 2007) to create a solid administrative context to the diffusion of these large-scale estates. Although reasonable differences between the countries, these policies presented in general similar aims, such as elevating the urban quality, providing affordable housing and promoting a new economy based on an efficient construction industry (Power, 1997).
Even if these urban plans involved also the construction of owner-occupied dwellings (Harris & Giles, 2003), but in most of the cases the main objective was the realization of large public housing areas for low income groups, built at the periphery of the cities where the cost of the land was lower.
The provision of apartments comprised single-family buildings, large-scale housing blocks, and, from the 1960s, high-rise constructions, which experienced an extraordinary diffusion in Western Europe for at least ten years (Wassenberg, 2012).
The estates, representing almost one third of the residential stock in Europe, offered finally a decent accommodation in a period of economic and social crisis, providing accommodations with good orientation, air quality and natural illumination, dramatically improving the living standard of the period.
The dwellings were imagined as spacious, efficient and healthy spaces surrounded by green areas and services, a good alternative to the high-density of the inner cities (Wassenberg, 2004), actuating the rational ideas of the pre-war modernism with the techniques and materials of the post-war period.
The social housing areas were often planned as idealistically independent centres, with educational, commercial and recreational facilities, and, in the beginning, they represented a good and appealing offer on the housing market (van Beckhoven et al., 2005).
From the 1970s, for the first time, the oil crisis and the consequent rise in heating costs imposed some reflections about the energy efficiency of the stock, with new policies concerning the insulation and the rational selection of construction materials (Priemus, 1986).

In the 1980s, relevant technical and operational problems started to manifest and, since then, regeneration programmes at different scales have tried to improve the quality of the estates, with some good examples, but still many challenges to address.
The technical and functional performances of the dwellings, unable to respond to the needs of a fast dynamic society, created dissatisfaction in the users, who gradually abandoned their accommodations.
Most of the estates, already degraded, faced a detrimental turnover in population when higher social classes moved out to leave space to weaker socio-economic groups.
Other relevant problems were connected to the age of the buildings that needed to be updated to the new quality and functional standards (Andeweg et al., 2007).
In addition, the strict urban rules that at the origin were intended to support the methodical growth of the areas, resulted as obstacles to the landscape improvement, leading to repetition and visual monotony.
Many estates also suffer of a negative public image (Wassenberg, 2004), seen as a problematic and unattractive area within the city.
In the past years, some authors have tried to rationalize the range of different problems affecting the social housing stock.
The result was the individuation of three main classes of problems (Turkington et al., 2004): problems connected with the stock itself, such as structural problems connected to poor characteristics that resulted in a detrimental image, management problems related to urban plans, management and investments, and finally the problems caused by a critical socio-economic environment (van Beckhoven et al., 2005).
Environmental problems, like energy consumption and pollution, have been subsequently added to the list, while "reputation" influences the local housing market and users' satisfaction, contributing to the decay of the neighbourhood or, on the opposite, being a trigger for improvements (Priemus, 2005; Wassenberg, 2004; van Beckhoven et al., 2005).
It is still no clear how and when the neighbourhood deterioration process starts (Priemus, 2005), with some authors believing in the influence of an "initial quality" (Prak & Priemus, 1986) so that if the initial condition is low, the deterioration of the stock may start earlier and/or progress more rapidly (van Beckhoven et al., 2005).
Prak and Priemus (1986) developed a model to describe the housing decline of the Post Second World War social housing estates indicating three "spirals of decay".
The first spiral is connected to technical decay, often inherent to the inadequate initial quality of the stock due to short construction times, poor materials and lack of experience in non-traditional construction.
Lack of proper management and maintenance come to add to the problematic technical condition. As a result, groups of residents with greater socio-economic strength leave the estate to be replaced by weaker socio-economically groups (young people, ethnic minorities, etc.). Because of this high turnover, social control is limited, the estate loses its reputation and its image, and this is when the spiral of social decay starts.
The income from the rents decreases, because of the vacancies, while the costs rise because of the increasing need for maintenance. The property owner might be obliged to be less careful in the allocation of vacant dwellings, with further effects on the social level.
This finally leads to the third spiral of financial decay. Because of vacancy, tenants' turnover and technical problems, income is lower than estimated, while expenses for repairs grow, causing relevant financial issues.
Technical, social and financial decay often prove to reinforce one another, in a vicious cycle. Once the social decay has spread, the turnover of tenants' increases and excessive vacancy emerges. The subsequent loss of income intensifies the lack of maintenance, resulting in technical problems.
Nevertheless, large housing estates still represent an important resource for the European housing market, being often the only economic viable choice on the market (Van Kempen et al., 2006). Many people are still positive about the presence of a large amount of green public spaces, about the design of dwellings (van Beckhoven et al., 2005), and because, due to the expansion of the cities, today they are often located close to the centres and they are supported by a good accessibility network.

2.3 The Italian perspective

The construction industry is currently experiencing a period of profound crisis aggravated by some endogenous factors, which are slowing down the recovery process while enlightening the limits of the sector.
There is a substantial need for innovative techniques oriented toward energy efficiency and quality performances while, in addition, it is fundamental to solve the critical conditions of the housing stock.
In Italy the buildings built more than 40 years ago amounts to the 36,5% of the total residential stock: 30,1% of buildings and 22% of dwellings were built before the Second World War, while 58,8% of buildings and 61,6% of dwellings were built after the war and until the 1990s, with a progressive increase in the number of dwellings per building (Table 2.1).

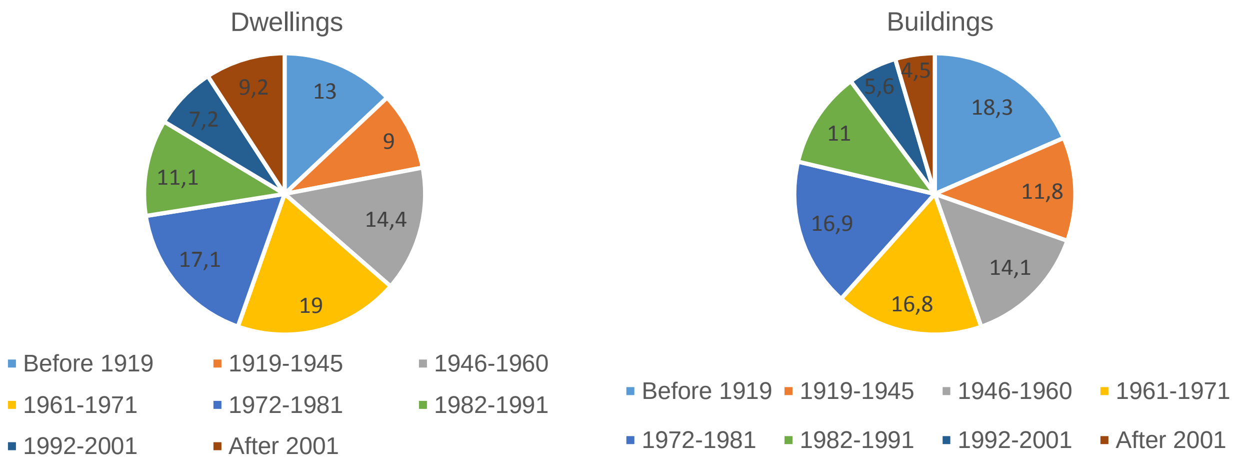


Table 2.1
Percentage of dwellings and buildings per period (Source: Cresme/SI data elaborations).

In 1986, the government registered that 3,5 million dwellings realized in the previous decades were poorly constructed and that 1.590.000 multi storey houses were at risk (Mezzetti et. al., 2003).
More recently, the condition of maintenance has indicated that more than the 22% of buildings has a conservation rate mediocre (19,9%) or poor (2,2%): in complex is about 2,6 millions of buildings with evident necessity of requalification with a clear correlation between the year of construction and the maintenance condition (Table 2.2).

	Excellent (%)	Good (%)	Mediocre (%)	Poor (%)	Total (%)
Before 1919	14,7	48,8	31,6	4,8	100,0
1919-1945	14,0	50,0	31,6	4,5	100,0
1946-1961	16,8	55,0	25,6	2,5	100,0
1962-1971	22,6	58,1	18,2	1,2	100,0
1972-1981	31,2	56,2	12,0	0,6	100,0
1982-1991	34,9	55,0	9,6	0,4	100,0
1992-2001	47,6	44,9	7,1	0,4	100,0
After 2001	71,9	25,0	2,9	0,2	100,0
Total	25,9	52,0	19,9	2,2	100,0

Table 2.2
Conservation rate in relation to construction periods (Source: Cresme/SI data elaborations).

If the CENSIS institute has estimated that the 40% of the Italian housing stock can be considered “old”, retrofit actions are still limited and they are often connected to sectorial problems (Table 2.3), losing the big picture of the building, which would require integrated interventions.

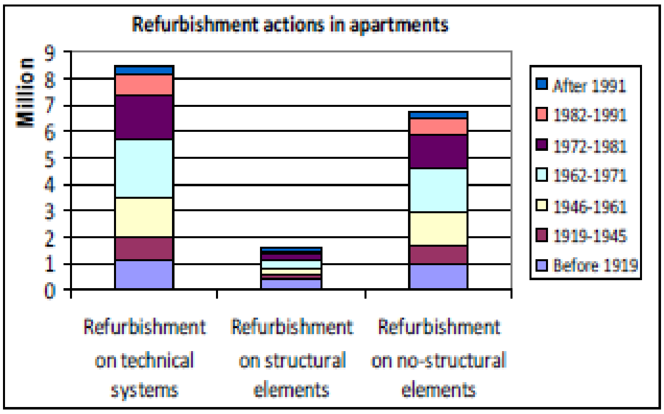


Table 2.3
Number of actions in Italian apartments divided by type and construction period (Source: ISTAT 2004).

Another relevant factor is that among European countries, Italy is one of the last for social housing supply. In 2006, it represented only the 4% of the total stock, in comparison with the 35% of Netherlands, the 30% of Germany and the 17% of France (Scenari Immobiliari, 2006). As a matter of fact, in Italy, social housing is still an experimental field of development (Pozzo, 2005) while home ownership corresponds to the 75% of the total stock, and for many years ensured economic turnover and financial benefits.
The scenario is completely different from the other European country, where the public sector and the private sector are two sides of the same strategy to provide housing supply, integration and socio-economic development.
The economic and social crisis in our country underlined the necessity of radical changes starting with the provision of social housing, today far away from satisfying the demand of the market.
Paradoxically, while the number of people in need of affordable housing is increasing, the social housing stock in Italy is diminishing because some institutes are progressively selling parts of the stock without replacing it with new dwellings in order to afford maintenance programmes.
Between the 1980s and the 1990s, 826.000 units, corresponding to the 3% of the social housing stock, have been put into the private market (Tosi & Cremaschi, 2001; Mezzetti et al., 2003). Starting from 1996, the sale process accelerated reaching a peak in 1998 when 17.000 dwellings were sold, while, in the same year, the production of social housing did not reach 10.000 units. As a consequence, between 1998 and 2000, the social housing stock decreased from 6,3% to 5,3% of the total housing stock (Pozzo, 2005).
This disposition resulted insufficient to balance the financial deficit of the institutes: the exploitation of social housing is not profitable and, consequently, the maintenance level and the investments decrease, together with the quality of the stock.
The problem of deterioration of the technical and functional quality occurs in particular within estates built between the 1960s and the early 1980s. Since the decay affects not only the physical but also the socio-economic sphere, new renovation processes and intervention strategies are urgently required.
Another relevant problem is the criteria to get access to a dwelling, which is not in line with the changing social structure, characterized by a high long-term unemployment rate and new emerging groups such as immigrants, cohabitating couples and elderly households. The result is that vulnerable social classes are not facilitated in the allocation process (Mezzetti et al., 2003).
The actions recently undertaken by the government, like the privatization process of the institutes and the transfer of the power to the single regions, did not generate substantial positive results.

It is also true that Italy is among the European countries that allocates the lowest national budget for welfare services, since most of the budget is given to the pension scheme, and far less funds are allocated to unemployment, families, health and the social sector.

On the contrary, the housing policy facilitates expansion of the ownership, excluding disadvantaged groups stating just fragmentized and temporary interventions. Policy for social assistance consists only of social rented houses for people in economic need supplied by housing institutes and the municipality; temporary accommodation for low-incomers and evictees supplied by local authority, housing benefits with income criteria supplied by the local authority and dormitories and shelters for homeless people supplied by the local authority or voluntary sector (Mezzetti et al., 2003).

In Italy, as well as in Europe, the theme of housing is back to be a social issues, while the contemporary family changes consistently over the years, requiring more spaces, services and performances, with a complexity and diversification that needs to be understood and interpreted in new articulated policies.

2.4 Managing the built heritage: definitions and problem statement

Some authors (Tenner & DeToro, 2008) have evaluated the possibility to "manage the quality" of a building, introducing eight factors, namely performance, features, reliability, conformance, durability, serviceability, aesthetics and perceived quality.

Despite the relevance of each of these factors in defining the quality or the lack of quality of a building, rarely the decision to intervene is motivated by a single reason, being usually affected by interlaced necessities.

Technical problems, for instance, manifest sometimes with a level of damage able to affect users' satisfaction. Other common reasons for dissatisfaction are the size of the apartments or the inadequate layout of the dwellings, due to the standards and requirements, consistently changed over the time.

With the shift in the age-profile of European population (BPIE, 2011), also accessibility and the elimination of architectural barriers have become important issues to address. Consequently, transformation strategies may also incorporate elevators, usually absent in buildings constructed until the 1960s.

Financial motives are also fundamental, since obsolescent and neglected properties, with low social image, can increase consistently their value if upgraded (Power, 2008). An action can improve the appearance, the performance and the efficiency of a building, increasing its attractiveness, thus the rent prices. Investing in energy efficiency renovation, for instance, has an appealing payback time, thanks to the benefits given by the reduction of expenses.

Finally, also the structural vulnerability of the building affects consistently the necessity of transformations, because of pre-existing elements and the eventual additional components to add to ensure the safety of the construction.

The basic issues to address can be summarized in seismic performance, construction cost and time, disruption and/or relocation of the users during the construction, long-term effect on building, and aesthetics, including considerations of historic preservation. Successful strategies should consider all of these factors, even if the final scheme is often determined by user-oriented visions rather than by simple technical demands.

It is fundamental to recognize that the loss of the performance capacities of a building, and consequently its degradation, are anyway part of the natural life process of a construction (Gruis at al., 2006). A friction within this model occurs when the event is not predictable or it is far below the acceptance criteria or the expectations of the users. In some of these cases, the consistency to the expected lifespan can be assured again through maintenance works (van der Flier & Thomsen, 2006).

The objective of a transformation process is instead a comprehensive and ideally endless extension of the life span of a building, throughout modifications of its physical, functional, architectural and ecological characteristics (van der Flier & Thomsen, 2006; Thomsen & van der Flier, 2008; Thomsen, 2011). Life-cycle extension is often more sustainable than replacement (de Jonge, 2005; Gruis at al., 2006), which must be considered as the last resort, and it is also coherent with the conception of the building as a set of different layers (Brand, 1995; Leupen, 2006), each one with a different useful life. The life span of a structure, for instance, is from 30 to 300 years, while the envelope can last only 20 years, due to reasons connected with architectural style and energy performances. This means that the external elements conclude their natural degradation process when the structure is still completely sound. In these cases, the replacements or upgrading of the components with a shorter life span can allow to the overall life-cycle extension of the building (Gruis at al., 2006).

Of course, there is not only one possible solution to intervene, and different procedures are defined to provide completely different results (Priemus, 2005).

The first important difference is between “refurbishment” and “retrofit”, since the first aims at restoring the initial performances of a building with the correction and repair of defects, while the second indicates the complex set of actions directed at conforming the building and its parts to the current standards. Again, “restructuring” is directed at improving the building and the surrounding environment, while “renewal” aims at modifying the neighbourhood in order to make it attractive for higher classes of users (Ouwehand & van Daalen, 2002). Finally, “replacement” consists in demolition and reconstruction of the buildings, used to promote economic growth and social control through the elimination of urban ghettos (Crump, 2012).

Even if often supported by the construction industry (Thomsen, 2011), demolition is not popular between the final users (Power, 2008) who do not participate to the reconstruction process (Crump, 2012).

From the environmental point of view, transformation processes are more efficient than replacements because they exploit all the pre-existing materials, requiring four to eight times less resources (Itard & Klunder, 2007; Thomsen & van der Flier, 2008) while demolitions are the biggest source of landfill by volume, with around 30% of the total (Power, 2008).

Existing buildings are a stored of embodied energy, consumed during the initial production and transport of materials (Dixit et al., 2010).

If it is undeniable that new constructions on the long run have better energy performances because of superior insulation and high quality materials, they also have a wider environmental impacts (Power, 2008), so that the difference in terms of energy savings with transformation processes is not substantial (Verbeeck & Cornelis, 2011).

The saving potential of the existing stock should also be considered in relation to the new construction rate, which is only the 1% every year, which means that in a period of 10 years only 10% of the stock will be at least at the level the current building regulations demand.

Consequently, transformation is the only possible and effective answer to upgrade the energy efficiency of the stock and to obtain relevant environmental benefits, reducing the energy demand of the whole building sector.

From a financial point of view, demolition and new construction is only worth and it is the last resort if the house is in such bad state that extensive, cost-intensive measures are needed, not justifying the investment (Thomsen & van der Flier, 2008).

Also buildings suffering of non-repairable structural problems or located in areas where supply exceeds demand are successful candidates for demolition and it is estimated that by 2050 the building stock will decrease of the 8% (BPIE, 2011).

On the other hand, there is still a big proportion of the stock that can be transformed into functional and efficient buildings using minimum non-renewable energy, producing minimum air pollution and construction waste, all with acceptable investment and operating costs, while improving the indoor environment for comfort, health and safety.

The issue is complex, encompassing a number of parameters such as the architectural design and construction, energy efficiency along with political support and incentives, socio-financial effects and users' behaviour.
An integrated design able to handle with all these factors is the objective of this research and of this thesis.

2.5 Discussion

The structure of ownership and occupancy has always a significant relevance on the ability to renovate.
Social housing is typically fully owned by the public sector but there is an increasing trend towards private involvement in many European countries, while in the Netherlands social housing is fully owned by private sector.
The mixing typologies of inhabitants and the low mobility rate are also factors implying more constraints and difficulties, with fragmented interventions on the territory.
For these reasons, the diffuse practice still focuses only on technical interventions, such as ordinary or extraordinary maintenance works, while integrated retrofit are normally seen as triggers of other mandatory improvements, thus increasing the costs of the intervention.
Despite that, many studies led to the conclusion that neighbourhood satisfaction depends mostly on housing satisfaction and on the reputation of the area, factors that should be considered in a retrofit programme (Wassenberg, 2004).
The studies also enlightened how the residents' involvement and housing preferences play a fundamental role within process, but the parties often underestimate them, exaggerating the efficacy of substantially technical intervention in generating happier residents.
It is instead more the image and the reputation of the neighbourhood to have influences on the satisfaction level and, if users are satisfied with their own house, they will feel more attached to the neighbourhood and the level of social safety might increase (Priemus, 2005).
The study of the factors influencing the preferences of the inhabitants, called "environmental aesthetics", is fundamental and can concern the visual quality of exteriors in relation or not to their surroundings (Nasar, 1992).
The image of neighbourhoods can be actively promoted, like any commercial product, thus the improvement of the aesthetical quality of existing deprived estates might contribute to the marketing of the whole area (Wassenberg, 2004).

3. SEISMIC VULNERABILITY OF THE BUILDING STOCK

3.1 Introduction

Most of the social housing heritage, built before the 1980s, suffers today of architectural and functional obsolescence and seismic vulnerability, raising questions about the future of the cities and their inhabitants.
In an era of environmental emergency and lack of resources demolition and reconstruction is not a sustainable alternative. A multi-purpose retrofit campaign is fundamental but the complex information to handle and manage require integrated and innovative solutions.
A consistent percentage of masonry and reinforced concrete buildings, old or recently built, cannot provide appropriate levels of seismic safety, because of the poor quality of the construction even before that degradation and aging of materials run their course (Rodrigues & Teixeira, 2006).
An aggravating factor is that earthquakes of significant intensity occur today in areas not traditionally considered seismically risky, revealing the limits of the approaches used to classify the territory and consequently enlightening the necessity to increase the safety levels for conventional buildings everywhere (Martelli, 2006).
Social and economic losses caused by earthquakes are not easily quantifiable but Dolce (2009) estimated that in Italy the expenses associated to seismic events are around € 2-3 billion per year, still without considering the incalculable damages related with the destruction of the historical and cultural heritage.
As said, some key causes are the obsolescence of buildings and their high seismic vulnerability, in conjunction with the late classification of the territory (Dolce, 2012), but also the inefficient quality control and the insufficient analysis of the degradation processes along the entire life cycle of the buildings resulted in less durability (Rodrigues & Teixeira, 2006) and lack of prevention measures.
Vulnerable buildings are a manifestation of the vulnerability of an urban system, since the response of the city can be interpreted as the sum of the single responses of its composing elements but also because they are the expression of the attitude of the community towards disasters and unexpected events (D’Amico & Currà, 2014; Gargiulo & Papa, 1993; Fistola & La Rocca, 2009).
This problem can be reduced designing consistently with regulations and promoting a campaign of seismic rehabilitation for existing buildings (Munari et al., 2011).
Fukuyama and Sugano (2000) indicated three possible strategies for seismic rehabilitation: recovering the original performances, upgrading them or reducing the seismic response of the building.
The selection of the most suitable strategy depends on several factors (Thermou & Elnashai, 2006), such as the structural typology and technology, the historical and functional importance of the building and the socio-economic issues connected with serious damages during and after an earthquake.
Therefore selecting the appropriate retrofit is a complex task with multiple possible choices in relation to the factors considered and their relative importance (Caterino et al., 2008).
While it is rare to find the “better” intervention on a general level (Caterino et al., 2007), typically the ratio between the costs and the performances achieved is determinant for the definition of the retrofit program.
This is one reason for the designers to propend for integrated approaches: a single intervention that solves a complex set of problems – architectural, functional, structural – and this synergy should improve the overall

characteristics of the building at the same time reducing the ancillary construction expenses. In this way, the costs associated with seismic retrofitting could be substantially reduced.
Caffrey (1988) defined “Intelligent” a building able to provide a “productive and cost effective environment through optimization of its four basic elements: Structures, Systems, Services, Management, and the interrelation between them”. In the same way, an “Intelligent retrofit” for existing buildings should offer an intervention that integrates all of the different performance requirements – such as structural safety, energy efficiency and architectural quality – optimizing the construction process and the expenditures.
The most consistent portion of social housing heritage was built before the 1980s, so in advance with respect to the introduction of the new regulations, with their specific requirements for the achievement of minimal levels of seismic safety. Moreover, buildings have a specific life cycle expectancy, generally around 50-60 years (Chapman et al. 2002), after which other weaknesses, such as the obsolescence of the technical apparatuses and of the architectural characteristics, must be considered for the quality of the cities and the satisfaction of the users.
Those buildings, obsolete or approaching disuse and demolition, can be an unexpected source for new projects (Chusid, 1993), either if demolished to make space for new constructions or if rehabilitated and reused (Langston & Lauge-Kristensen, 2013).
Demolition and rebuilding is a feasible option in order to build seismically safe houses with all the modern comforts, services and performances, improving the life quality and the internal and external environment but despite that, the process has high prices in terms both of costs and of natural impacts. A research of the Preservation Green Lab (2011) declared that demolition today is not a sustainable solution: it increases the ecological emergency producing residuals and wastes difficult to remove and to reuse while the subsequent reconstruction of a new “green” building requires 80 years to compensate the use of natural resources. A sustainable use of the resources would be instead to requalify the existing building heritage (Langston et al., 2008) in order to obtain an overall increase of the performance of 30%, with the provision of additional services and spaces.
The cost of the conversion is lower due to the presence of pre-existing elements and materials and rehabilitation takes around half of the construction time necessary for demolition and reconstruction of the same floor areas, reducing the financing, the effects of inflation and the risk of collateral events and related expenses (Johnson, 1996). Moreover, a problem not to underestimate is the necessity of temporary relocation of all the inhabitants of the building.
The director of Habitech in the 2012 declared that it is possible to capitalize the money invested in retrofit in relatively short time considering for instance the consequent increase in value of the construction and the new environmental quality achieved.
In this way, the marketability of a building is improved and, in presence of seismic retrofit, the security for lives and properties, the reduction of possible losses – in terms of building heritage but also in equipment – and the guarantee of business continuity, attract potential buyers so that the correlated advantages are more significant than the retrofit expenses (Egbelakin & Wilkinson, 2008).
In this chapter the author will present the most important considerations to approach the theme of structural retrofit. The first paragraph will describe the most diffused construction typologies in European countries, attempting at classifying the residential heritage with different criteria. Consequently, it will be presented the condition assessment method for existing buildings and the retrofit procedures.

3.2 Construction features of the building stock

The European building stock is an assortment of different constructive typologies, which is probably first factor to consider before planning a structural retrofit.

The residential heritage, in particular, presents some typical and common features within the territory (TABULA, 2010), with few exceptions that can be assimilated to simple deviations.

The building methods are usually determinant to define the construction type of the residential buildings, so as the cultural and historical period is significantly interrelated to the construction technique adopted (Moe & Smith, 2012). Over the centuries, the changes in construction techniques have been driven by innovations in the use of materials and resources, modifications of the cultural aesthetic, changes in the socio-economic conditions, or the necessity to minimize the costs and the construction time (TABULA, 2010). Still some construction principles and techniques span over the centuries, presenting a greater degree of permanence, and they are still used in parallel with the newer ones. Prefabricated wall panels, for instance, were very popular in the post-war years coexisting with brick masonry systems (Andeweg et al., 2007).

Despite the difficulty of a strictly chronological classification, below there is an attempt to present the construction characteristics of the stock, divided for different historical period (Table 3.1).

Historical period	Characteristics
Pre-industrialized before 1860	The architecture is based on historical types verified by experience, while legal requirements are basically inexistent. The materials used are usually found locally and handcrafted. Masonry load-bearing walls are used to build tall, big rooms.
Industrial revolution 1860-1900	The industrial development induces a rapid expansion of cities and the standardization of the construction process, with new technological achievements (steel construction, reinforced concrete, etc.). This period is characterized by different territorial manifestations.
Old Traditional 1900-1920	The buildings have solid external walls of locally produced bricks, on brick foundations and large areas of cement rendering. Roofs are made of timber, pitched, and covered with slates or clay tiles, with mainly cast iron gutters and fall pipes. Ground floors are often solid to kitchen and storage areas, while the upper floors are realized in timber.
Interwar 1920-1940	The period is characterized by increased industrialization of materials, use of cost efficient techniques and standardisation on national level. Cavity external walls, still of local bricks, are gradually introduced around the 1930s. Concrete strip foundations and damp courses are common. The idea of industrialised building systems has been developed since the interwar years by the Modern movement (Moe & Smith, 2012), which imagined large homogeneous residential developments with open public areas and parks. The apartments have good daylight and ventilation with a strictly functional layout.
Prefabricated 1945-1950	After the Second World War, there is an urgent need to replace the houses destroyed and to provide homes for people returning to civilian life. There is insufficient time to provide either materials or suitable labour to meet the requirements of the traditional building methods. However, there are many factories suitable for redirection towards the mass production of new materials. The new components are prefabricated in the factories, using non-traditional materials, in order to reduce the time and skilled labour required on site. They are frame constructions, cladded with a variety of materials, including asbestos, steel, aluminium, and concrete, although some are with an external layer of traditional brickwork. A minority this production is intended to have a short or restricted life span.

Traditional **1945-1960**	During the era of prefabrication, there are still some traditional buildings, gradually increasing as more skilled labour and traditional materials are available. Most Authorities resume the same design used before the war, but some flat-roofed dwellings start to appear. Flat roofs are of timber or concrete, felt or asphalt-covered, with parapet walls to the edges. Apart from the roof, the rest of the construction is identical to the traditional dwellings, but with different maintenance problems due to the absence of the pitched roof. In the same years, initial improvements to the road network permit less reliance on the use of local materials.
Rationalised Traditional **1950-1975**	Fresh efforts are made to improve efficiency and speed in the building process, with the combination of modular, factory produced components, and traditional practices on site, rationalising the traditional approach. Probably the best known approach is the cross wall construction, involving brick/block gables, and separating walls, set out to receive infill panels to front and rear elevations. These panels were produced off-site and often only required the addition of window glass and external door hanging after installation. Such panels were generally timber framed, covered with a variety of materials, providing functional, sunny and airy houses.
Non traditional **Industrialised** **1950-1975**	The rate of house construction is not able to provide the appropriate supply, while slum clearance programmes and the post-war population boom create a huge housing deficit. A vast number of modular building systems are developed using new techniques, materials and factory produced and assembled components. They generally consist of a structural frame of timber, steel or concrete, with infill panels, or sometimes with an outer skin of brickwork to create a more traditional appearance. In many cases, concrete was the basic material for both the structure and external shell of the dwelling. Most building systems are designed to allow greater flexibility. At the peak of the industrialised period there are over two hundred systems on offer, some of which are promoted by companies who had previously only supplied an individual building component, and simply attempted to provide a complete system around it, with insufficient experience of the overall problems connected to housing design and construction. Non-traditional approaches to house construction all essentially involve an attempt to shift some aspects of the construction process away from the site, to a factory. Hence, they are sometimes referred to as “industrialised” building techniques. These industrialised methods considerably reduce the construction period and labour costs, however, they imply a number of unforeseen problems.
The prosperous years **1975-1990**	The period is carachterized by the first awareness of energy efficiency due to the energy crisis. This leads to higher quality of constructions and choice of materials. The first campaign of refurbishments of older, historical buildings is undertaken.
Housing Today **1991-today**	Even if the industrialised approach lost popularity, there is an increasing use of timber-framed structures, which were originally inspired by it. The key factor is the new ecological and energy awareness followed by national and international legislation, which leads to technological achievements and the use of renewable resources.

Table 3.1

Construction characteristics of the building stock per period

Other possible classifications of the residential heritage could differentiate traditional and non-traditional construction, prefabricated or built on site houses, but also material used or the geographical diffusion.

With reference to the structural retrofit, it could be interesting to evaluate the structural design with the division between loadbearing external walls, skeletal frames and box-frame structures, which imply a consistent difference in the way in which the roof is supported (Meijs & Knaack, 2009)

Loadbearing external walls constitute both the structure and the space enclosing component and the facade bears the weight of the roof and internal floors. The walls are solid, constructed from monolithic or composite elements, perforated with limited opening for light and air created using horizontal beams as lintels and arches (Knaack et al., 2014).

In skeletal frames, the horizontal elements are supported by linear elements, the columns. This structure may consist of beams and pillars made of reinforced concrete, steel or timber. This form allows the division of the wall into loadbearing structure and infill, which is the space-defining element (Knaack et al., 2014). Skeleton structure offers the possibility for wide-span openings and fully glazed facades. Reinforced concrete frames in particular, used since 1890s, and well established from the 1920s (Macdonald, 2008), were extensively used in the post war years, due to the high price and shortage of steel (Giebeler et al., 2009)

Loadbearing internal traverse walls, also known as box-frame or cross-wall, became popular in the post war years. Driven by the potential of simplified concrete construction, this method allowed to build as quickly as possible and it was used in industrialised and high-rise estates developments (Macdonald, 2008).

It is mostly prefabricated or in-situ reinforced concrete, however other constructions, such as internal masonry walls, are possible. This structural system permits greater building depths and is therefore regarded as more economic (Giebeler et al., 2009). Moreover, it offers the possibility of unrestricted facade design, with larger amount of glass area, lightweight walls and precast concrete elements.

Another interesting classification concerns the building envelope, considering the roof, the exterior wall, the ground floor and the windows. The components construction can be in general categorised as heavy/ massive construction and lightweight construction (Table 3.2). The variations between these main categories across Europe are vast, depending for instance on the region, the period, the availability of materials, or building traditions.

Classification	Sub-type	Characteristics
Massive construction (masonry, concrete)	**Masonry**	Masonry consists of natural or manufactured elements, where the choice largely depends on the availability of each material and the requested performance. Clay brick is predominant in central and northern Europe, particularly in areas where clay was easily found in the proximity of building sites. This technology is present in house construction throughout different periods, until current constructions. The external walls above ground level consist of clay brickwork for the 95% of buildings built in Europe from the industrial revolution to 1920s (Giebeler et al., 2009). Traditional bricks are solid and their dimensions may vary according to local format. Natural stones, such as limestone, sand stone, granite, are used on the base of the walls and at critical connections, such as corners and windows. Masonry walls of natural stones are common in Southern Europe traditional residential buildings, prior to 1920s. Numerous examples of this construction method are available, as it was the most common technique until the Second World War. The external masonry walls carry their own load, as well as the loads of the roof, the stories and their contents, by compression. A minimum thickness was specified for the top floor and increased for every additional storey, where the steps serve to bear the timber floors and the roof (Giebeler et al., 2009). The shape of the roof may vary from simple double-pitched roofs to more complicated shapes. They are usually covered with clay roof tiles, however, other materials, such as concrete roof tiles, fibre-cement sheets, or organic material are also used. In later years, reinforced concrete floors and flat roof are also common.
	Cavity walls	Walls comprising two leaves of masonry with an intermediate air cavity are called cavity walls. This type of construction has been known since

		earlier years, developed in interwar years (Giebeler et al., 2009) and became standard in the post-Second World War period. It presents certain advantages in comparison to the solid masonry wall because the air cavity improves the thermal insulation properties of the wall and it provides better weather protection preventing saturation. Additional advantages are material savings and shorter drying times. The reduced stability is solved with bonders or tiles of galvanized steel incorporated in the masonry. The outer wall is usually of higher strength, fired above sintering point, for better weather protection at increased costs. The timber floors are often replaced with reinforced concrete ones. After the oil crisis in the 1970s, the cavity was used to place the compulsory insulation layer. Nowadays, double-leaf walls with cavity insulation are still constructed with various materials in different parts of Europe.
	Lightweight masonry	After the 1920s, the use of solid clay bricks left space to lightweight masonry units, such as hollow bricks, vertically or horizontally perforated, as well as lightweight clay bricks. Apart from better insulation values, they allowed for larger formats at the same weight per unit, resulting in faster bricklaying and, thus, faster and cheaper construction processes. To cope with the lower compressive strength, in high-rise buildings, they were often combined with skeleton or loadbearing wall structure. Examples also exist where the stacked hollow, lightweight units were filled with concrete, to improve their strength. Perforated bricks with plaster finishing are the predominant technology in southern Europe (Andeweg et al., 2007).
	Prefabricated concrete panels	Prefabricated concrete panels were developed because the material was long lasting and flexible to different sizes and shapes, while prefabrication provided quick and economical mass production. The panels were pre-casted with the size of a room and an internal insulation layer, fixed in situ with concrete or welded steel plates. Generally, no other cladding or colouring is added, so the final result is dark grey, sometimes with decorative texture. The main disadvantage of the technology, other than the thermal and weather performances, was the dimension limits of the prefabricated panels, able to provide only non-flexible dwellings. Nevertheless, this is the prevailing building technique for buildings of the post-war period in northern and east European countries, such as Germany, Poland, Hungary and Denmark. Pre-cast concrete walls are also encountered in the Netherlands, France and Belgium (Andeweg et al., 2007).
Lightweight construction	**Timber frame construction**	Timber framed walls are structural elements which can be provided of different infill, such as brick or stone. The main disadvantages of this technology are related to the aging and damaging of the material and to the energy performances. Timber frames were also widely used for non-traditional building systems (Diamant, 1965). The infill in this cases was made with plywood, insulation, plywood, water barrier membrane. The cladding can be of horizontal or vertical overlapping strips of different materials (Mehta et al., 2008). Good weatherproofing of the timber frame wall was essential, as the veneer is not expected to be entirely watertight. Brick veneers are the most common; however, other materials, such as stone, are possible. The popularity of brick veneer lies in its aesthetic appeal and durability (Mehta et al., 2008).
	Lightweight facade panel	In non-traditional buildings, prefabricated lightweight elements are commonly used to form the outer wall. The longitudinal facade between the traverse loadbearing walls consists of storey-high prefabricated timber or aluminium frame, incorporating the windows and opaque elements.

		After the oil crisis, the use of double-glazing became more common. The opaque elements, as the parapet of the windows, are sandwich panels consisting of asbestos cardboard/plasterboard and insulation. The performance, both thermal and acoustic, of this facade type is very poor, particularly considering the buildings built prior 1970s. Additionally it has similar problems to the panel buildings, with regard to narrow and non-flexible floor plans.

Table 3.2
Classification of constructions in relation to the characteristics of the envelope.

To conclude, the organisation of construction types does not strictly depend on geographical area or country, as it is possible to encounter the same construction in several areas.
Nevertheless, some construction or variations can be seen as typical, due for instance to building tradition or material availability.
The presented research will focus on the construction methods used after the Second World War and on the structural typologies more common in Italy, namely masonry and concrete frame with masonry infill.

3.3 Condition assessment for buildings

Post-Second World War houses were erected with the ambition to be a spacious, comfortable, well designed, an appealing alternative to the city-centre dwellings (Wassenberg, 2012). Nevertheless, problems manifested themselves in the early decades after their construction and already in the 1980s, serious operating problems and high vacancy have been observed, in many countries.
Considering the structural issues, existing buildings may not comply with requirements of current regulations for different reasons: components could have deteriorated over the years; the buildings could not have been designed to resist earthquake loads; the seismic design of the building provides a resistance not measured with the current codes, etc.
It is important to assess the condition of a building and to provide a retrofit intervention if necessary with individual investigation and evaluation.
The understanding of the construction and the identification of problems are the first and the most important steps in the refurbishment design process because they determine the need for interventions and their potentials. Furthermore, the existing structural performance defines the possible improvements, so that the poorer the performance is the greater the room for upgrading.
Condition assessment for existing buildings generally includes the following steps: initial inspection and appraisal, review of documents, preliminary evaluation, detailed investigation, and reporting.
Rapid visual screening involves a quick assessment based on visual inspection to identify and inventory the vulnerable buildings, which are consequently studied and evaluated to identify the extent of inadequacy with respect to the prescribed standards.
The steps for a rapid visual screening procedure are: planning, execution and interpretation of the results.
The main uses are:

- To identify if a building requires further evaluation for its seismic vulnerability.
- To assess the seismic damageability (probability of damage) of the building and the need for seismic retrofit.
- To identify simplified retrofit schemes for the buildings for which further evaluation is not considered necessary or not found to be feasible.

Since it is a visual inspection, and subjective, the results may occasionally vary consistently from that of detailed analysis. Additionally it allows detecting mostly surface defects, giving low reliability.

In order to facilitate the seismic evaluation of a building, it is necessary also to collect relevant data about drawings, enquiry, design calculations, soil reports, inspection reports, reports of previous investigation, previous repair works, any complaints by the occupants etc.
The data of the building includes also the plan, necessary elevations, the basic architectural features, material properties and their deterioration and other helpful information.
During the preliminary evaluation, the checks to be investigated are classified into two groups: configuration related and strength related.
The configuration of a structure is evaluated through the interpretation of the load path in relation to the geometry of the construction and its vertical or horizontal discontinuity. Other considerations are about the presence of weak or soft storey, about the mass distribution and the presence of adjacent buildings.
Strength related checks are simple calculations of quantities that reflect the demands in the primary members due to the seismic forces. The calculations are based on the base shear and the distribution of the base shear to the floor levels of a building.
The plan irregularities of re-entrant corner, out-of-plane offset and non-parallel systems need not be checked under evaluation statements. The centre of mass and the centre of rigidity can be approximately evaluated.
Once the condition assessment is complete, the building can be analysed with a detailed investigation.
A number of tests are available to study the condition of the material in a structure. The tests are grouped as follows.

a) Non-destructive tests: the material is tested without causing any damage to the structure.
b) Intrusive tests: a sample of the material is removed for the evaluation, consequently adequate repair is necessary to compensate for the removal of the sample.
c) Destructive tests: the structure is tested to failure to gather information for similar types of buildings.

A retrofit programme should be implemented starting from the results of the condition assessment.
The principal decision is about repairing, retrofitting or demolishing in relation to the importance, the target life, the extent of deficiency of the building, the economic viability of the intervention, the availability of materials and technical resources, and the expected life span after retrofitting.
In general, if the condition assessment revealed that the safety level of the building is adequate, then some repair and regular maintenance can ensure adequate performance during a future earthquake.
If the safety level resulted to be inadequate, hence retrofit is necessary and the strategy planned should be feasible and economically viable.
Finally, if safety is grossly inadequate and the building is in imminent danger of collapse in the event of an earthquake, the building has to be declared unfit for use and it has to be demolished when the retrofit scheme is not economically viable or feasible.
When retrofit is considered the best operative option, the next steps have to be undertaken:

1. Selection and design of retrofit strategies.
   A retrofit strategy refers to any action of increasing the strength, stiffness and/or ductility of the building. The selection of an option depends on the available technical expertise and inconvenience during the intervention. The strategies can be grouped under global and local strategies. The final scheme should be cost effective.
2. Verification of the retrofit scheme.
   The scheme should be ensured through structural analyses of the retrofitted building and that the selected scheme satisfies the identified objectives. Alteration of the load path, redistribution of the forces and changes in the failure modes after retrofitting need to be studied. The scheme should be viable in terms of costs and execution.
3. Construction.
   The effectiveness of the retrofit scheme greatly depends on the quality of construction. Hence, the construction as per the suggested details and specifications is imperative.

4. Maintenance and monitoring.
   They are necessary to achieve the performance during a future earthquake.

3.4 Introduction to seismic retrofit

The purpose of seismic retrofit is to enhance the structural capacity (strenght, stiffness, ductility, stability and integrity) so that the performance of the building can be raised to the desired level to withstand the design eathquake.
The decision to retrofit or not stands on many factors.
It is likely that many ordinary buildings will be found seismically unsafe but the financial implication of a complete retrofit campaign can be important.
It is also true that the aim of retrofit is to raise the capacity to 100 percent just in relation to the importance of the buildings so for lifeline buildings while for the other buildings it can be decided on the expected remaining usable life.

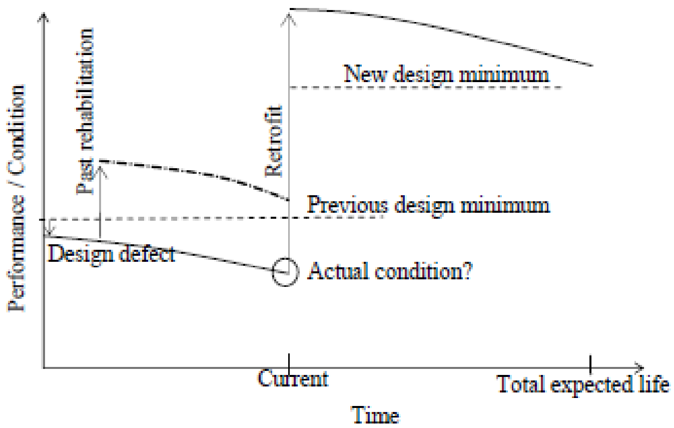


Figure 3.1
Evolution of actual performance or condition of a building.

The general goals of seismic retrofit can summarized as:
- To increase the lateral strength and stiffness of the building
- To increase the ductility in the behaviour of the building to avoid the brittle modes of failure
- To increase the integrate actions and the continuity of the members
- To eliminate or reduce the effects of irregularities
- To enhance redundancy in the lateral load resisting system to eliminate the possibility of progressive collapse
- To ensure adequate stability against overturning and sliding.

The conventional objective of the retrofit for an “engineered building” are based on measurement of relevant quantities: demand to capacity ratio for both vertical and lateral loads, and the interstory drift.
A retrofit strategy is a technical option for improving the strength and other attributes of resistance of a building or a member to seismic forces.
The retrofit strategies can be classified under global and local strategies: a global retrofit targets the performance of the entire building under lateral loads, while local retrofit targets the seismic resistance of a member, without necessarily affecting the overall resistance of the building.

The grouping of the retrofit strategies into local and global are generally not be mutually exclusive. For example, when a local retrofit strategy is used repeatedly it affects the global seismic resistance of the building. In many cases, it may be necessary to combine both local and global retrofit strategies under a feasible and economic retrofit scheme.

When a building is found to be severely deficient for the design seismic forces, the first step in seismic retrofit is to strengthen and stiffen the structure by providing additional lateral load resisting elements.

In Table 3.3, some of the most common global retrofit strategies with their advantages and disadvantages.

Retrofit	Description	Merits	Demerits	Comments
Addition of infill walls	Addition of infill walls in the ground storey is a viable option to retrofit buildings with open ground storeys. Due to the “strut action” of the infill walls, the flexural and shear forces and the ductility demand on the ground storey columns are reduced.	-It increases lateral stiffness of a storey. -It can support vertical load if adjacent column fails.	-It may have premature failure due to crushing of corners or dislodging. -It does not increase ductility. -It increases weight.	-Low cost. -Low disruption. -Easy to implement
Addition of shear walls, wing walls and buttress walls	Shear walls, wing walls or buttress are added to increase lateral strength and stiffness of a building. The shear walls are effective in buildings with flat slabs or flat plates. Usually the shear walls are placed within bounding columns, whereas wing walls are placed adjacent to columns. The buttress walls are placed on the exterior sides of an existing frame.	-It increases lateral strength and stiffness of the building. -It may increase ductility.	-It may increase design base shear. -Increase in lateral resistance is concentrated near the walls. -Necessity of distributed and symmetrically placed walls.	-It needs integration of the walls to the building. -High disruption based on location, involves drilling of holes in the existing members. -Design issues connected to integrate the wall to the building and to design their foundations.
Addition of braces	A steel bracing system can be inserted in the frame to provide lateral stiffness, strength, ductility, hysteretic energy dissipation or any combination of these. For an open ground storey, the braces can be replaced in appropriate bays while maintaining the functional use.	-It increases lateral strength and stiffness of a storey. -It increases ductility.	-Connection of braces to an existing frame can be difficult.	-Passive energy dissipation devices can be incorporated to increase damping, stiffness of both. -More effective for flexible frames. -If added from the outside, least disruption of the building use.
Addition of frames	A new frame can be introduced to increase the lateral strength and stiffness of a building. Similar to a new wall, integrating a new frame to the building and	-It increases lateral strength and stiffness of the building. -It may increase ductility.	-It needs adequate foundations and appropriate integration.	- It needs integration of the frames to the building to work properly.

	providing foundations are critical design issues.			
Reduction of irregularities	The plan and vertical irregularities are common causes of undesirable performance of a building under an earthquake. Some typical irregularities are discontinuous components of the lateral load resisting system, torsional irregularities, and eccentric masses.	-It can reduce force and deformation demands in the members to acceptable levels.	-It requires partial demolitions.	-The appearance and the utility of the building can be substantially affected.
Reduction of mass	This option can be considered instead of structural strengthening.	-It results in reduction of lateral forces.	-It requires heavy demolitions and changes.	-Realized by demolishing additional storeys, replacing heavy cladding or heavy equipment, or change in the use of the building.

Table 3.3
Common global retrofit strategies.

Conventional seismic design practice permits the reduction of forces for design below the elastic level on the premise that inelastic action will provide significant energy dissipation potential, and enable the structure to survive a severe earthquake without collapsing. This inelastic action is typically intended to occur in spatially detailed critical regions of the structure, dissipating substantial energy but also resulting in significant damage to the relevant member.
As a response, in recent years, considerable attention has been paid to research and development of seismic dissipative devices, which can provide passive, active or semi-active control.
Structural analyses are usually performed using a suitable software. The steps involve developing a computational model of a building, applying the external forces, calculating the internal forces in the members of the building, evaluating the deformations of the members and finally interpreting the results.
The calculations for conventional objectives of seismic retrofit can be performed by linear elastic methods among which the equivalent static analysis, based on application of static lateral loads at the floor levels, is the simplest to undertake.
On the contrary the response spectrum method is bases on dynamic characteristics, such as mode shapes, and it is so called dynamic method, being recommended for certain types of buildings.
Both those methods are linear elastic, so they suffer of some deficiencies because they are not able to reflect the inelastic deformation capability or ductility of members and buildings. Additionally, the sequence of yielding of sections and subsequent redistribution of loads in the building are not available for either of those methods.
For seismic retrofit of buildings, a new analysis approach based on quantifying the performance is gaining popularity. The performance of a building is measured by the state of damage under a certain level of earthquake, expressed as a performance level that, for the building as a whole, is quantified by the inelastic drift of the roof.
The performance levels are discrete damage states identified from a continuous spectrum of possible damage states. A building performance level is a combination of the performance levels of the structure and the non-structural components. The structural performance levels considered are Immediate Occupancy (IO), Life

Safety (LS), and Collapse Prevention (CP). The three levels are based on the behaviour of the lateral load resisting system under increasing base shear.
So the objective of seismic retrofit is to reach a targeted performance level under a certain level of earthquake. So, while the traditional approach to seismic design of a building is force-driven, the performance based approach is based on quantifying the inelastic deformations of the members and the building as a whole under the seismic loads. This approach starts from the consideration that deformations or strains are better measures than stresses or forces to assess damage. To quantify inelastic deformations, a performance based approach requires a nonlinear lateral load versus deformation analysis.
Pushover analysis and nonlinear time history analysis are respectively the static and dynamic methods of nonlinear analyses.

3.5 Discussion

A retrofit campaign is of primary importance to increase the safety and the life quality of the cities, and residential districts can transform from a critical issue to a strategic resource of revitalization (Grecchi, 2008).
Considering the costs involved, it is imperative to have seismic evaluations of a building both for the existing and retrofitted conditions, to justify the selected strategies.
Structural safety assessment is carried out through non-linear methods of analysis, which are mainly based on the modelling techniques developed for studying new buildings. However, the inevitably poor knowledge of the structural details and of the material mechanical properties, makes the results of the numerical analyses not fully reliable.
Based on the condition and deficiencies, repair and retrofit strategies are selected.
In general, when a building is severely deficient for the design seismic forces, it is preferred to select a global retrofit strategy to strengthen and stiffen the structure. Consequently, if deficiencies still exist in the members, local retrofit strategies are to be selected. Beyond this recommendation, it is not prudent to prescribe a retrofit strategy as a generic application, since each one has merits and demerits in relation to the project.
A retrofit has to be selected after careful considerations of the cost and constructability and a proper design is essential to reduce the disruption for the occupants.
Technical considerations must consider the failure mode in a member after retrofitting, any alteration of the load path, possible overstressed members, and, finally, the additional loads on the foundation.
Tierney (2005) showed how the seismic rehabilitation can assume a key role in the risk mitigation and prevention of disasters considering that the earthquakes are more and more random in place, time and intensity (Nuti & Vanzi, 2003). Stevens and Wheeler (2008) underlined that improving the quality of the building heritage guarantees the sustainability of the construction industries and of the cities.
To maximize the achievements of the retrofit and its sustainability, the complexity of these objectives and requirements need to be handled: architectural features, energy performances, emissions reduction and structural behaviour must be part of the same integrated intervention with consequent high costs involved.
Nuti and Vanzi (2003) declared that in order to make retrofit a good investment, the ratio between costs and reduction of the risk should be calculated. Despite that, large scale and long term systematic campaigns, on a national or regional level, have not been undertaken yet.
On the other hand, the broad scale of the intervention faces the necessity to break the visual monotony widely imposed to the social housing districts, leaving space to individuality and variety for more vibrant and dynamic realities. In this sense, a favourable aspect is that social housing is usually free of any historical and cultural constraints typical of the building heritage, allowing a broader operative margin with multiple options.

4. STATE OF THE ART: RETROFIT OF RESIDENTIAL BUILDINGS IN EUROPE

4.1 Introduction

Most recent studies and personal experiences teach us how the image of the city changes continuously over the time (Rossi, 1978). The introduction of a dimension of temporariness in the field of built environment is coherent with the vision of the building as a living organism, able to develop in relation to user's needs, and the progressive modification can be interpreted as the natural development of a design project.

Besides this aspect, interventions on the built heritage are today necessary to upgrade the housing estate to current living and technological standards, because of the emergence of new social and cultural realities (UNI 8289, 1981).

Many cities in Europe are trying to promote urban policies against land consumption, encouraging the recovery of the existing heritage (Bennicelli Pasqualis, 2014). The first country to act in this direction was France, with interventions of upgrading of the performances and quality standards, and the promotion of maintenance programmes, with the final objective to enhance the image of buildings and neighbourhoods.

These approaches reach the greatest efficiency when reversible, because only in this way they ensure environmental friendly actions with the possibility of dismantling.

The intervention should improve the flexibility of the existing construction with a correct balance between planning for the present and planning for the future.

A change in the user typology is already happening because of the disaggregation of the traditional family, for the different forms of social mobility and for the emergence of modern forms of nomadism. This phenomenon opens new considerations about the current building and urban standards, which need to be updated in order to respond to the requirements of an unspecified group of users that changes over the time and belongs to different social and cultural realities.

The traditional “room” has given way to “fields”, able to promote higher permeability in both private and collective life. Some recent studies verified the results of proving more space but with lower specification, giving more options to define the use over the time (Till & Schneider, 2005). Another option is to design spaces with adjustable configuration or equipped walls able to rationalize the space in different ways along the time, within a permanent or a temporary structural frame.

If the buildings are not conceived anymore as static and unmodifiable objects, at the same time the interventions of modification should not be expensive in terms of time and economic and material resources: the design of the intervention should promote velocity, lightness, safety and recyclability (Zambelli, 2004) other than reversibility and flexibility.

The analysis of the state of the art showed as lightweight interventions achieved using dry stratified construction technologies of structure/cladding/finishing, are a widespread approach to renovation and requalification both for superficial/two-dimensional action, aiming at determining better environmental conditions through the application of additional layers to the envelope, and volumetric/spatial actions intended as high-level transformations. These types of intervention overcomes the necessity to relocate the dwellers during the construction process and they are less problematic for the structural capacity of the existing building.

Along with the necessity to respond to the new housing demand – with different users, different uses and different living styles – the renovation of the existing built heritage is enhanced by the need to limit the land use and the horizontal expansion of the city, which experiences an exponential acceleration after the Second World War until the eighties.

Although research suggests that there is a number of sustainable urban forms (Williams et al., 2000), in Europe the debate resulted in the promotion of the “compact city” model, a high-density mixed-use city with clear boundaries (Burton et al., 2003; Williams et al., 2000) and a good system of connections.

To date the model has appeared to be efficient in terms of transport, at the same time promoting a sustainable use of land, containing urban sprawl (Hagan, 2000) and preserving the areas in the countryside at the same time recycling the one in the centre (McLaren, 1992).

In social terms, compactness and mixed-use are associated with diversity, social cohesion and cultural development while population density is able to support local services and businesses while granting a balanced exploitation of the infrastructure systems (Jabareen, 2006; Williams, 2000).

This chapter will present forty-nine project of renovation of the residential heritage, a range of best practices able to illustrate the complex panorama of the state of the art in Europe.

Each case will be deeply analysed and evaluated with a data sheet; synoptic views and tables will provide key interpretations and an exhaustive panorama of options and approaches.

The study will finally highlight the leading role of the envelope within retrofit interventions.

4.2 Research methodology

The interpretation of the state of the art in the field of residential renovation moves from the analysis of forty-nine European projects realized in the last decades. These episodes have been selected as “best practices” to illustrate the most convincing and successful approached and the solutions adopted in the different European countries.

The analysis takes into account residential buildings renovations, considering different typologies of housing and target users; few cases show a substantial change of use, and this often coincides with the reuse of abandoned and ruined constructions.

Every project is presented through a data sheet, specifically created in order to show the main characteristics of the building, the principal elements of the design concept and the consequent results and achievements.

The data sheets have constituted the primary tool to produce synoptic tables and analysis diagram, which finally provide the general overview of the current European practice.

Every building is presented with a set of images of the post-intervention configuration and a set of general information, such as the location, the architects, the client, etc.

The data sheets are organized in relation to housing typologies to create an index easy to consult and interpret; within this research, the housing typologies detected are, in order: point house, terraced house, row house, tower house, patio house, gallery house, mixed and itinerant.

Another important descriptive factor is the “action” used that, as explained in the introductive paragraph, can belong to two main families: superficial/two-dimensional actions and volumetric/spatial actions.

Figure 4.1
First section of one of the forty-nine data sheets.

The data sheet shows also the “strategy” of renovation individuated from a range of ten different possible approaches, which have been deduced from the literature review and from the personal considerations of the author.

The ten strategies, and the relative symbols, are explained below:

- Absorption: the intervention completely covers and absorbs the existing building or, vice versa, the new part is contained in the volume of the existing building.
- Continuity: the intervention presents no sharp rift with the language of the existing building in terms of shape, dimensions or architectural features.
- Contrast: the intervention presents marked differences from the existing building in terms of shape, dimensions, technological or architectural features.
- Filling: the intervention fills a gap between two or more buildings or between different parts of the same building.
- Integration: the intervention and the existing building collaborate and integrate to shape a new overall image and perception of the construction.
- Parasite: the intervention forces the creation of temporary or permanent relationships with the host building in order to complete themselves.
- Rebalancing: the intervention acts as a counterbalance for the existing building creating an overall equilibrium in the new perception.
- Remodelling: the intervention operates a substantial modification on the original building that results drastically transformed.
- Selection: the intervention works through punctual and specified action to upgrade the features of the existing building.
- Stratification: the intervention acts as an additive layer, with different possible depth, modifying the original architectural features and performances of the existing building.

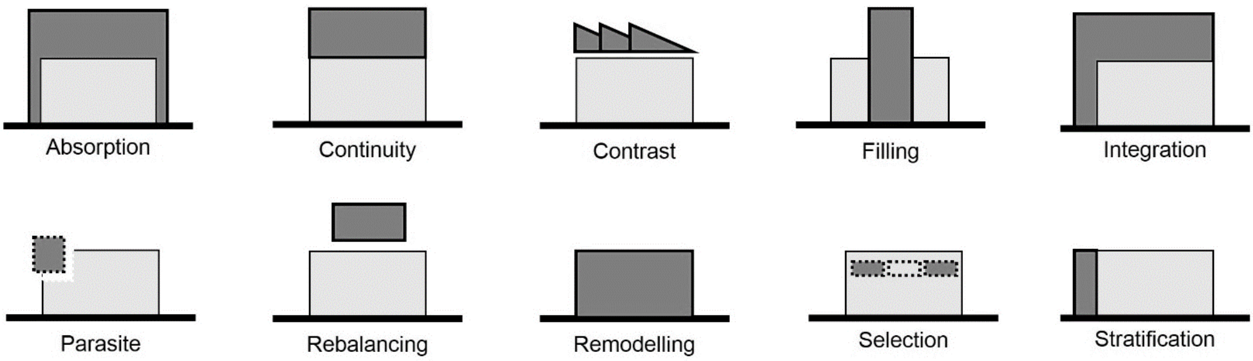


Figure 4.2
Strategies of interventions on residential heritage.

The second section of the data sheet summarizes the main data concerning the design concept, the construction process and the final results of the renovation project.

Data collection:

The pilot project aims at creating a green roof that could be also an urban square for the inhabitants of the social housing building. The approach of densification is interpreted in a sustainable way, in terms of materials and solutions (TEC.1, TEC.2).
The two social housing buildings are redesign for a rooftop expansion: the first step was the demolition of the pitched roof in sheet metal and subsequently two series of terraced houses with balcony access were built on the ninth floor.
The new houses are made with wood and metal and they have green roofs for better thermal performance, especially in summer, and in order to allocate a private garden for each of the apartment underneath (ARC.1, FUN.3, TEC.1, TEC.2).
The small constructions have access routes and they share a communal building with its square-garden (FUN.1, FUN.2, FUN.3), generating a urban micro-environment with a panoramic view of the city and of the distant mountains (ARC.2, ARC.3).
Although the construction process suffered of many management problems (CON.1, CON.3), the inhabitants were able to restore the architectural dignity of the project personalizing the environment and the apartments. The narrow spaces create spontaneously many occasions of meeting and cohesion, with the actual requalification of the social housing buildings promoting again a living style based on sharing (SOC.1, SOC.2, SOC.3).

Summary:
STR.0) Structure > Light strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Radical strategy
FUN.0) Function > Medium strategy
TEC.0) Technique > Medium strategy
CON.0) Construction > Ineffective strategy

Figure 4.3
Second section of one of the forty-nine data sheets.

Within the text, every record is classified using codes related to six different fields: structure, architecture, society, function, technique and construction.
Each of these fields is sub-divided again into three sub-fields, which are a further form of interpretation of the information showing its relevance to the project.
The codes refer both to the existing building and to the achievement after the intervention.

STR.0)	Structure
STR.1)	It describes the structural characteristics of the existing building and its extension; it comprehends the materials used, the structural scheme and the static and dynamic properties of the construction.
STR.2)	It indicates every reference to the structural capacities of the building before and after the intervention or to the external constraints or structural threats, such as seismic or geotechnical constraints.
STR.3)	It represents the condition of obsolescence, the structural deficiencies and the retrofit actions applied on the existing construction, in connection or not with the renovation intervention.
ARC.0)	Architecture
ARC.1)	It indicates all the details connected to the historical, environmental, architectural and urban background of the existing building.
ARC.2)	It is connected with the recognisability and attractiveness of the area or of the existing building, considering also the perception and the visual relationships with the surrounding environment.
ARC.3)	It refers to all the design choices concerning the intervention of renovation of the residential building, which influence the architectural features of the building and, in general, its perception.
SOC.0)	Society
SOC.1)	It indicates the enhancements obtained, voluntarily or not, with the application of the intervention considering also factors such as the social cohesion and security.
SOC.2)	It is used for every reference to the introduction of new supplies for the target users; it is also connected to the themes of densification and participation.
SOC.3)	It expresses the level achieved after the intervention of renovation in relation to the social sustainability and liveability of the area.
FUN.0)	Function
FUN.1)	It indicates the provision of new services and facilities for a wider group of users, the new functional quality of dwellings and their availability for a wider target of users.
FUN.2)	It individuates situation of mixed use, connected both with residential function or with other relevant functions, such as education, business, healthcare, etc.
FUN.3)	It indicates the improvement of connections and accessibility contributing to improve the attractiveness of a wider target of residents.
TEC.0)	Technique

TEC.1)	It is used in relation to the data connected with the use and choice of materials and technologies.
TEC.2)	It is related to the improvement in the energy performance of the building, to the use of natural energy resources and new technical and technological equipment.
TEC.3)	It is related to the life cycle assessment of the building, including the degradation, the ageing and the maintenance plans.
CON.0)	Construction
CON.1)	It is used to indicate the construction process and approach adopted in relation to the context of the existing building.
CON.2)	It is related to the cost of the intervention and to any method adopted in order to limit the expenses or to capitalize the action.
CON.3)	It explains the construction choices and the material used to limit the construction times and so the nuisance for the inhabitants and the indirect cost connected.

Table 4.1

Definition of codes and sub-codes.

Thanks to the use of codes it was possible to define the *level of success* achieved by the intervention in relation to the six fields mixing the information relative to the building ante and after intervention.

LEVEL OF SUCCESS	ACTIVITY	
0) Unknown strategy	Structure	Unknown strategy
	Architecture	Unknown strategy
	Society	Unknown strategy
	Function	Unknown strategy
	Technique	Unknown strategy
	Construction	Unknown strategy
1) Ineffective strategy	Structure	Lacking of a primary step of evaluation of the capacity of the existing building and of the external constraints. Ineffective selection or use of the structural materials.
	Architecture	Wrong or incomplete interpretation of the surrounding context; unattractive or inadequate selection of the architectural features.
	Society	Failure of the strategy for inadequate interpretation of the societal conditions and no participative process. Degradation, crime of the area and missing sustainability.
	Function	No additional services, new functions and/or accessibility patterns. No mixed use in terms of functions or target users. Ineffective design and consequent use.
	Technique	Inadequate selection of the technology in relation to the performance and to the surrounding environment. Missing attention on the sustainability of the project and on the energy performances. Easy degradation of the elements.
	Construction	Management problems during the construction process, late delivery and/or unforeseen indirect or direct costs.
2) Light strategy	Structure	Evaluation of the existing structure and minor lightweight additions, both superficial and three-dimensional.
	Architecture	Minor modification of the architectural features of the building. Relative attention to the existing context in terms of permanence of the same visual and physical relationship.
	Society	Interactions with limited societal groups; permanence of the same provision of dwellings and facilities.
	Function	Permanence of the same provision in terms of facilities and services; no new accessibility schemes.
	Technique	Absence of relevant enhancement of the performances of the building; the choice of materials relatively consider the maintenance, aging and degradation processes.
	Construction	The construction plan is not specifically intended to reduce the construction time and costs.

3) Medium strategy	Structure	Partial demolitions of non-structural elements for distributive reasons with no relevant modification of the existing structures; light addition on the roof with independent structure.
	Architecture	Increase in the interaction with the context with some modification of the appearance of the building.
	Society	Enhancement of the liveability and sustainability of the housing estate.
	Function	Provision of new facilities for the existing users and societal groups; mixed use and new accessibility schemes for private users.
	Technique	Enhancement of the energy performance of the building with the introduction of new insulation layers or performing materials.
	Construction	Consideration of strategies to reduce the costs and the time during the construction process with the selection of particular processes, structures and materials.
4) Heavy strategy	Structure	The structure is modified consistently in order to carry new loads and elements or as a consequent of the individuation of environmental constraints.
	Architecture	Significant interaction or modification of the context provoked by the intervention.
	Society	Provision of housing for a wider societal group, often mixed, with new pattern of sustainability in the area.
	Function	Provision of facilities and new services for a wider societal group, often in correlation with mixed use or target, new accessibility patterns for the users.
	Technique	Use of prefabricated technologies, dry technologies and/or lightweight technologies. High increase in the energy performance of the building connected with the use of natural resources.
	Construction	Exploitation of prefabricated construction techniques and application of innovative strategies to limit the construction time and costs.
5) Radical strategy	Structure	Substantial demolitions and modifications of the existing structure with addition of new consistent structural elements.
	Architecture	Radical modification of the interaction with the context and/or substantial change of the architectural appearance of the building.
	Society	Consistent strategy of modification of the living standard of the area, sometimes developed with participate design process. New users and societal groups are considered and involved.
	Function	Provision of new spaces, facilities and services, often in mixed use. The accessibility results to be substantially modified.
	Technique	Prefabricated and high performing technologies are used to achieve the best environmental performances. New strategy for the production of energy with the use of natural resources.
	Construction	The construction process has radical positive effects on the reduction of costs and time. The realization of the intervention does not influence the life of the inhabitants and their activities.

Table 4.2
Definition of the levels of success.

The final section of the data sheet provides information concerning the materials and the solutions used.
The information obtained are collected in material palettes relative to structural solutions, cladding and finishing and details.
The palettes can be seen as part of a catalogue of choice, to use in relation to the actual condition of the building and to user's requirements.
The instrument can be progressively updated with new technological solutions or materials in this way becoming a dynamic and adaptive tool.

The final objective of this operation is to keep a margin of variety in the final solutions, relieving the designer from the choice and giving to the occupant much more freedom in the definition of the parameters and performances of the dwelling.

Figure 4.4
Third section of one of the forty-nine data sheets.

4.3 Best practices

TYPOLOGY	DATA SHEET	PROJECT	COUNTRY	YEAR
Point house	1	Aichinger house, Hertl Architects	Austria	2010
	2	Dovecote Studio, Haworth Tompkins	Great Britain	2009
	3	Gründerzeithaus M30, Peter Zinganel	Austria	2008
	4	House in Morchiuso, Castelletti & Viganò	Italy	2011
	5	House within a house, FNP architects	Germany	2005
	6	La ruina habitada, Jesùs Castillo Oli	Spain	2006
	7	Maison Saignelegier, Dubail & Begert	Switzerland	2013
	8	Studio Posehuset, Svendborg architects	Denmark	2010
	9	The White house, WT architecture	Great Britain	2010
	10	Villa Rotterdam, Ooze	Netherlands	2010
Terraced house	11	Black Pearl House, Studio Rolf & Zecc	Netherlands	2010
	12	Casa do Conto, Pedra Liquida	Portugal	2011
	13	Didden Village, MVRDV	Netherlands	2006
	14	Heliotrope over elevation, Bang architects	France	2010
	15	Lude House, Grupo Aranea	Spain	2011
	16	M03 house renovation, BAS architects	France	2013
	17	Neo Leo, Luderwaldt	Germany	2006
	18	Over elevation in Rue Daumer, Le Bihan	France	2010
	19	Over elevation in Rue Delbet, Le Bihan	France	2006
	20	Passive renovation De Kroeven 505, Aramis	Netherlands	2011
	21	Peugeot blocks, Lucien Kroll	France	1995
	22	Symbiont, FloSundK	Germany	2004
	23	St. Johanns-Platz 25, 4056, Wenger	Switzerland	2003
	24	Tayson House, Kraus & Schoenberg	Great Britain	2008
Row house	25	Bondy Loggias, Laurent Pillaud	France	2009
	26	Falconer Rehabilitation, Atelier Jens Freiberg	France	2009
	27	Fordsiedlung der LEG, GBR arkitekten	Germany	2010
	28	La Golette, Atlante SA	Switzerlands	2011
	29	Leeuw van Vlaanderen, Heren 5	Netherlands	2005
	30	Minimum impact house, JDS Architects	Germany	2008
	31	Republic housing complex, Castro & Denissof	France	2003
	32	Rue Daubin 26-27-29, Group 8	Switzerland	2011
	33	Square Vitruve, Atelier Du Pont	France	2013
	34	Stadthaus Dreiheiligen, Daniel Fuegenshuh	Austria	2007

	35	Surefit, Ipostudio	Italy	2008
	36	Treehouse Bebelalle, Blauraum	Germany	2010
	37	UFO, Florian Danner	Germany	2009
	38	Zwinglistrasse 9 and 15, Viriden + Partner AG	Switzerland	2003
Tower house	39	Fahle House, KOKO architects	Estonia	2007
	40	La Chesnaie, Lacaton & Vassal	France	2014
	41	Le Bois le Prêtre, Druot, Lacaton & Vassal	France	2011
	42	Over elevation, Studio Albori	Italy	2007
	43	Torenflat, Frowijn de Roos	Netherlands	2010
Patio house	44	Hellwagstraße 6-8, Lutter Heinz	Austria	2003
	45	Park Hill, Hawkins-Brown & Egret West	Great Britain	2011
	46	Spitalgasse 25, Wien 9, Lutter Heinz	Austria	2003
	47	Veilige Veste, KAW architects	Netherlands	2012
Gallery house	48	Wijnand Nuijenstraat, van den Brink en Tupker	Netherlands	2007
Mixed	49	Dillenburgh, Heren 5	Netherlands	2010

Table 4.3

Index of the data sheets related to the best practices.

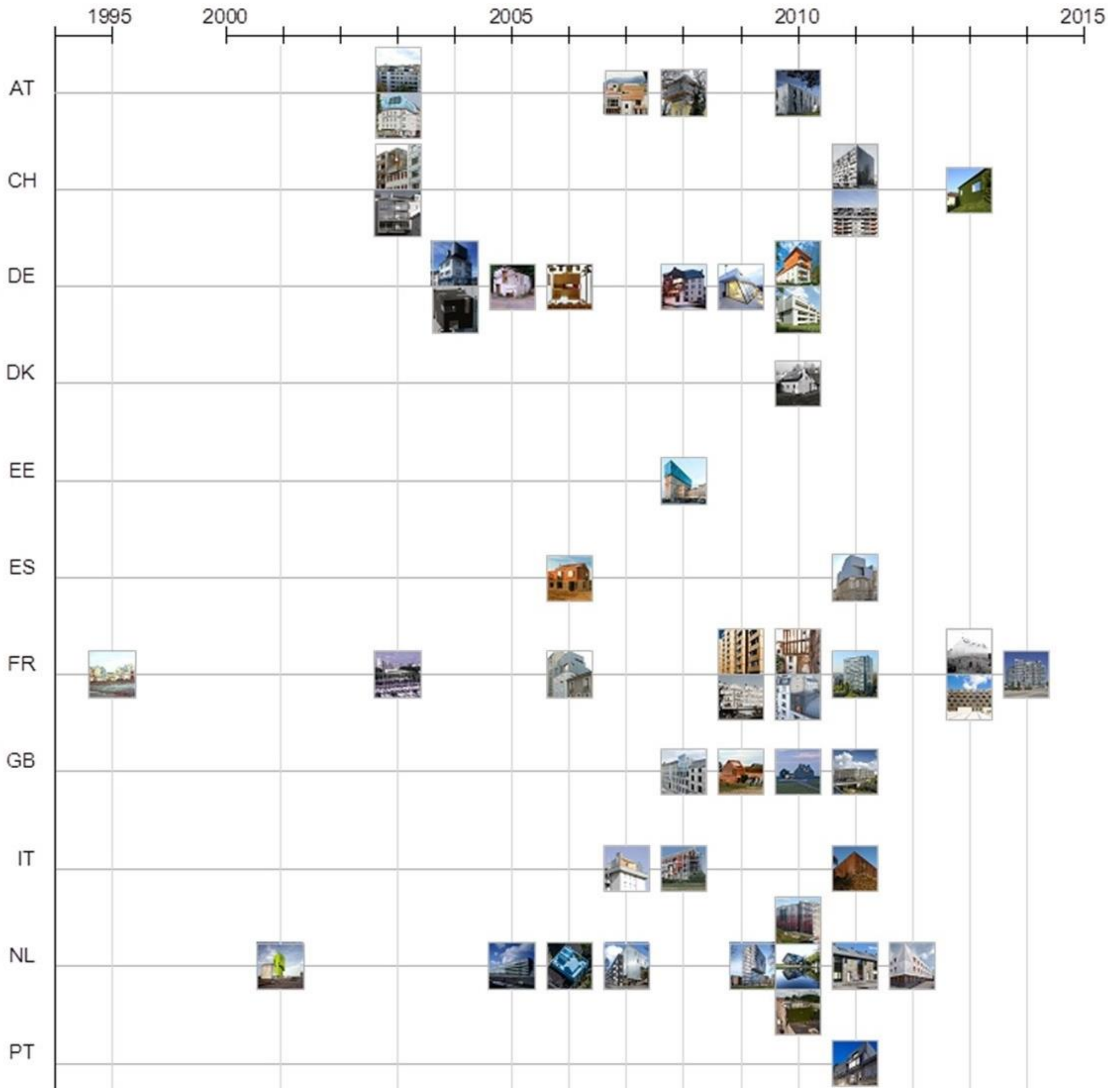


Figure 4.5

Locations and periods of the selected best practices

DATA SHEET N.1

Action: superficial/two-dimensional

Stratification

An outdoor new curtain to explore the flexibility of facades.

General data:

Project: Aichinger house
Site: Kronsfort, Austria
Architect: Hertl architects
Client: Andreas and Astrid Mitter-Aichinger
Construction: -
Renovation: 2010
Typology: point house
Target: two families

Data collection:

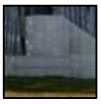
The building was once a single floor building and was transformed into a duplex of contemporary design developed on two floors with external concrete stairs (ARC.2, FUN.1, FUN.3, TEC.1).
The existing roof was removed and the external walls are completely wrapped in grey curtains, which create the effect of lightness and serenity (ARC.2, TEC.1).
Allowing for privacy, the curtains can be pinned back just like interior curtains to allow light to come in through the windows. From afar, the exterior looks like rippling concrete flowing in the wind or the bent sheets of steel (ARC.2, ARC.3, SOC.3, TEC.2).
The design wraps the whole exterior of the building in the light grey fabric, rendering the layout and form of the interior hidden from the outside viewer (ARC.3).
Partings in the facade correspond with the windows to allow daylight into the apartments. At night the residence are lighted like a paper lamp.
As well as the usual bedroom curtains, this fabric can be drawn closed to provide more privacy and protect from the bright sunlight. I do not think, it's a practical idea, but looks elegant and stylish (ARC.3, TEC.2).
By applying a material which is normally reserved for the indoors, the project explores the flexibility of facades and skins.

Summary:
STR.0) Structure > Light strategy
ARC.0) Architecture > Radical strategy
SOC.0) Society > Unknown strategy
FUN.0) Function > Light strategy
TEC.0) Technique > Medium strategy
CON.0) Construction > Unknown strategy

Material palette:

Grey textile

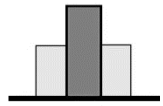
White textile



Concrete

DATA SHEET N.2

Action: volumetric/spatial



Filling

A house within the ruins of a house.

General data:

Project: Dovecote Studio
Site: Suffolk, Great Britain
Architect: Haworth Tompkins
Client: Aldeburgh Music
Construction: -
Renovation: 2009
Typology: point house
Target: mixed

Data collection:

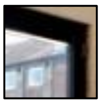
The building is a part of an extension of a campus for Aldeburgh Music erected in derelict industrial buildings on the Suffolk coast (ARC.1, ARC.2).
The new form expresses the internal volume of the Victorian structure as a monolithic Cor-ten steel house prefabricated and craned into position (STR.1, ARC.3, TEC.1, CON.1).
A large north light roof window provides even light for artists, while a small mezzanine platform with a writing desk incorporates a fully opened glazed corner window that gives long views over the marshes towards the sea (ARC.2, TEC.2).
The single volume can be used by artists in residence, by musicians as rehearsal or performance space, by staff for meetings or as a temporary exhibition space (FUN.1, FUN.2).
Only the minimum necessary brickwork repairs were carried out to stabilise the existing ruin prior to the new structure being inserted (STR.2, STR.3).
Decaying existing windows were left alone and vegetation growing over the dovecote was protected to allow it to continue a natural process of ageing and decay (STR.3, TEC.3).
The interior walls and ceiling of the space are lined with spruce plywood to create a timber box within the Cor-ten shell (ARC.3, TEC.1).

Summary:
STR.0) Structure > Medium strategy
ARC.0) Architecture > Light strategy
SOC.0) Society > Light strategy
FUN.0) Function > Light strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

Material palette:

Cor-ten

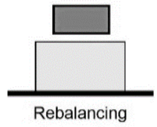
Spruce plywood



Glass

DATA SHEET N.3

Action: volumetric/spatial



A sustainable use of a historical building.

General data:

Project: Gründerzeithaus M30
Site: Graz, Austria
Architect: Peter Zinganel
Client: private
Construction: 1875
Renovation: 2008
Typology: point house
Target: single family

Data collection:

The house has a neo-renaissance style and is located in the historical centre of the city (ARC.1, ARC.2).
The final design wants to suggest a new coexistence between the existing and the new addition in order to promote a sustainable use in the historical centre as a form of high quality custody of the architectural and cultural value of the area (ARC.1, ARC.2, ARC.3).
The wood always represented a fundamental construction material for the old city and the new expansion wants to underline this relationship as an element of the valorisation and protection (TEC.1).
High quality design and realization, connected with long term maintenance and inspection, are the key features of the design plan (TEC.2, TEC.3).

Summary:
STR.0) Structure > Medium strategy
ARC.0) Architecture > Medium strategy
SOC.0) Society > Unknown t strategy
FUN.0) Function > Unknown strategy
TEC.0) Technique > Medium strategy
CON.0) Construction > Medium strategy

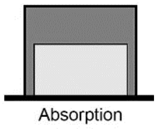
Material palette:

Wooden framed structure

Wooden panels with light grey painting

DATA SHEET N.4

Action: volumetric/spatial



A complete new appeal for the house.

General data:

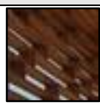
Project: House in Morchiuso
Site: Como, Italy
Architect: Marco Castelletti, Patrizia Viganò
Client: -
Construction: 70s
Renovation: 2011
Typology: point house
Target: two families

Data collection:

The house was originally designed with the language and the materials of the tradition, such as the complex pitched roof (ARC.1, ARC.2).
The purpose of the restructuring has been the search for a solution to make the two completely independent units and to reorganize the internal layout of accommodation with the recovery of the attic (FUN.1).
Having demolished the pitched roof, the existing perimeter walls have been erected in order to recover the plane of the roof and create a flat roof (STR.1).
The new tire has a limit of the outer perimeter walls of the house and, at the back, the retaining wall of the ground; this roof defines a large square table, to which were attached metal vertical structures that support the coating wood which encloses the volume (ARC.3, TEC.1).
The double row, formed by the walls of the house and the front grill of wood, generates double-height spaces, which remain as a transition space between the inner rooms and the garden (FUN.3).
Inside the geometry is still strong, with the contraposition of light and dark colours (ARC.3).
On the terrace a wooden solarium and a water room, with a small Turkish bath and a connection with the mobile glass roof with inserted solar photovoltaic systems (FUN.1, FUN.2, FUN.3, TEC.1, TEC.2).
The construction was developed in three phases so the family, moving from one apartment to the other was able to stay in the building during the entire construction process (CON.1).
The visual connection and continuity with the surrounding environment is strong (ARC.2).

Summary:
STR.0) Structure > Medium strategy
ARC.0) Architecture > Radical strategy
SOC.0) Society > Unknown strategy
FUN.0) Function > Heavy strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

Material palette:



Grill of larch wood

White painting

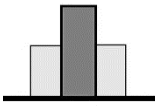
Panels anthracite coloured

Water

Glass and photovoltaic panels

DATA SHEET N.5

Action: volumetric/spatial



Filling

A house within a house.

General data:

Project: House within a house
Site: Stuttgart, Germany
Architect: FNP architects
Client: private
Construction: 1780
Renovation: 2005
Typology: point house
Target: single family

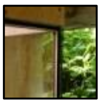
Data collection:

This is an adaptive reuse of a building partially destroyed during the Second World War and only reassembled for minor use in the period since the war (STR.3, TEC.3).
The building owner wanted to convert the building into a showroom, but the condition of the building made a renovation hard to finance as an upgrade (STR.3, TEC.3, CON.2).
The solution was to place a wood framed inner house inserted into the structure (STR.1, TEC.1).
The historic building is protected from collapse by the structure of its wooden insert, which lines-up precisely with the original windows on the outside: while it does not touch the original facade, it provides valuable support to the roof and outer walls (STR.2, STR.3).
Inside, it houses a beautiful modern dwelling thanks to an implanted wooden frame (ARC.2, FUN.1, TEC.1).
The results are striking and make a wonderful statement about the embodied historic, economic, and material energy presents in older structures.

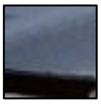
Summary:
STR.0) Structure > Heavy strategy
ARC.0) Architecture > Light strategy
SOC.0) Society > Unknown strategy
FUN.0) Function > Light strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

Material palette:

Timber panels



Glass



Metal

DATA SHEET N.6

Action: superficial/two-dimensional

Selection

A ruin adapted to live.

General data:

Project: La ruina habitada
Site: Palencia, Spain
Architect: Jesús Castillo Oli
Client: Fernando Gallardo
Construction:
Renovation: 2006
Typology: point house
Target: loft

Data collection:

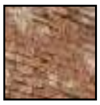
A place full of spirituality and an eccentric idea are at the base of the design (ARC.1, ARC.2).
The project was not a building to rehabilitate or restore but rather a ruin to adapt to live (STR.1, STR.2, STR.3).
The house is divided in two spaces, the inhabited area and the engawa, a space halfway between interior and exterior taken from Japanese culture (ARC.3, FUN.1, FUN.2).
The house becomes a mix in every way: the rural (brick) with urban (weathering steel and glass), the occidental with oriental (TEC.1).
One of the challenges was to build a shower to 6 meters high, giving the feeling of being under the rain. The house has no decorative items, and all the elements were designed by the architect except the sofa and chaise longue of Le Corbusier.
The windows turn into the paintings of the house with the landscape and the villagers (ARC.2, ARC.3).

Summary:
STR.0) Structure > Heavy strategy
ARC.0) Architecture > Medium strategy
SOC.0) Society > Unknown strategy
FUN.0) Function > Light strategy
TEC.0) Technique > Medium strategy
CON.0) Construction > Medium strategy

Material palette:

Weathering steel and glass

Timber



Bricks

DATA SHEET N.7

Action: superficial/two-dimensional

Stratification

A new formal connection with the surrounding environment.

General data:

Project: Maison Saignelegier
Site: Saignelegier, Switzerland
Architect: Dubail and Begert
Client: dB
Construction: 1974
Renovation: 2013
Typology: point house
Target: single family house

Data collection:

The building was renovated following the current energy requirements (TEC.2) using different materials: one facade, facing the surrounding fields, is covered by an artificial grass skin while the other three are and the roof are covered by dark corrugated fibre cement panels (ARC.3, TEC.1).
In this way the project suggests a deeper visual and physical connection both with the natural and built environment (ARC.1, ARC.2, ARC.3).
Social areas dominate the first floor with an open space that performs as living, dining and kitchen areas connected to a generous terrace; three bedrooms and a bathroom complete the plan. On the ground floor there is a sequence of service areas such as garage, storage and a bathroom that serves two rooms.
Interiors are kept simple mainly painted white while wooden ceilings contribute to the warm ambiance (ARC.3, TEC.1). The front door leads to a spiral metallic staircase placed in a green painted room.

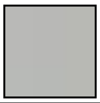
Summary:
STR.0) Structure > Unknown strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Unknown strategy
FUN.0) Function > Unknown strategy
TEC.0) Technique > Light strategy
CON.0) Construction > Unknown strategy

Material palette:

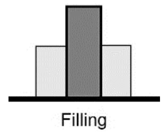
Artificial grass skin

Corrugated fibre cement panels

Wooden ceiling



White painting

DATA SHEET N.8	
 	**Action: volumetric/spatial**  A project both contextual and innovative. **General data:** Project: Studio Posehuset Site: Farum, Denmark Architect: Svendborg Architects Client: private Construction: - Renovation: 2010 Typology: point house Target: mixed

Data collection:

This studio for an artist is realized preserving old building with its fine plastered walls and contrast this by adding a single element, an element which is entirely covered with black anodized aluminium with a roof extending up above the previous roofline. Thus the outside world became ever-present (ARC.1, ARC.2, ARC.3, FUN.1, TEC.1). One side of the gabled interior has been finished entirely in mirrors to reflect views into the studio from skylights in the opposite side of the pitched roof. The new element is one homogeneous element in contrast to the white plastered facades of the old house (ARC.3, TEC.1, TEC.2). The interior works as an enlarged window mirror and an optical space: in this way is possible to achieve various depths in a relatively small space (TEC.2). Three asymmetrical light openings provide a special atmosphere (ARC.3, TEC.2).
The roof and the facade of the new building is conceived as a single unit, where solar collectors, sheets, and windows are in the same level (TEC.2).

Summary:
STR.0) Structure > Light strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Unknown strategy
FUN.0) Function > Light strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Medium strategy

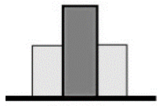
Material palette:

	Black anodized aluminum panels
	Fine plaster
	Mirror
	Wood

DATA SHEET N.9

Action: volumetric/spatial



Filling

A ruin integrated with a modern residence.

General data:

Project: The White house
Site: Isle of Coll, Greit Britain
Architect: WT architecture
Client: -
Construction: 1773
Renovation: 2010
Typology: point house
Target: single family house

Data collection:

The building has undergone a contemporary renovation after being abandoned for 150 being the perfect backbone for a new house (STR.1, ARC.3).

The challenge was integrating a crumbling ruin with a modern, environmentally sensitive home.

A fractured façade forms the perfect bookend for the new building, contributing great character and history while protecting the new home from the brutal Atlantic winds (ARC.1, ARC.2, TEC.2).

The massive stonewalls of the original home were doomed to failure as they were set on top of a sandy foundation and further eroded by treasure hunters searching for buried gold (STR.2, STR.3).

The new home huddles within the confines of the immense walls and branches out with a glass-lined living room at the home's core (TEC.1).

The other wing is buffeted by a large dry stacked stone wall. Lighter materials such as wooden beams and steel provide basic and locally sourced low-impact building elements while reducing the energy needed to ship materials to the site (TEC.1, TEC.2, CON.1, CON.2, CON.3).

The home also takes advantage of passive design strategies to lower its energy demand. A large bank of windows allows daylight to shine on the well-insulated black riven slate floor, which in turn warms the upper stories on either side. The original stone walls shield the home from the prevailing winds and provide a sheltered courtyard. The home is designed to be naturally cooled, and a green roof over the center of the home helps maintain its internal temperature (TEC.1, TEC.2, TEC.3).

Summary:
STR.0) Structure > Heavy strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Unknown strategy
FUN.0) Function > Light strategy
TEC.0) Technique > Medium strategy
CON.0) Construction > Medium strategy

Material palette:

Dry stone wall

Scottish larch stained black

Glass and steel

DATA SHEET N.10

Action: volumetric/spatial

Remodelling

Preserving the soul of the house and creating a new skin.

General data:

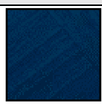
Project: Villa Rotterdam
Site: Rotterdam, Netherlands
Architect: Ooze
Client: -
Construction: 1991
Renovation: 2010
Typology: point house
Target: single family house

Data collection:

The redevelopment of the house is obtained by wrapping a new skin over the existing house (ARC.3).
The original building experienced a first extension in 1991 and again in 2003, with three more rooms and new facilities, creating the perception of a set of buildings merged together in an eclectic architectural form.
The design uses elements typical of the traditional Dutch farms, such as the green roof and the black stained wooden planks in a standard width to give more coherency with the surrounding built landscape (ARC.1, ARC.2, ARC.3).
The two main side walls of the original villa are extended reaching the new maximum height of 11 meters, creating new living spaces enveloped in a new skin (STR.1, CON.1).
The plan is reorganized around a central void, while a new staircase serving the first and the second floor.
The faces and the folds of the new envelope are defined in relation to the possibilities and the benefits for the internal spaces (ARC.3).
The new skin has also the structural duty to carry the new loads of the additional floors and roof to the foundation (STR.1, STR.2).
Prefabricated solid timber panels were used for the structure of the skin –roof, walls and floors- in order to speed up the construction process at the same time building with high precision (STR.1, STR.2, TEC.1, TEC.2, CON.1, CON.2, CON.3).
This structure can be perceived also from the inside, where the old and the new merge in a gradual transition and with different relationship of dominance in relation to the floor (ARC.3).
The objective was to rediscover the vernacular architecture introducing a new dialogue between the tradition and the new languages of architecture (ARC.3).

Summary:
STR.0) Structure > Heavy strategy
ARC.0) Architecture > Radical strategy
SOC.0) Society > Light strategy
FUN.0) Function > Light strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

Material palette:



Black stained wooden planks

Green roof

Prefabricated solid timber panels

Glass

DATA SHEET N. 11


Action: volumetric/spatial


Stratification

An “Escher-like” renovation.

General data:

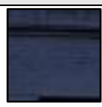
Project: Black Pearl House
Site: Rotterdam, Netherlands
Architect: Studio Rolf and Zecc Architects
Client: -
Construction: 1900s
Renovation: 2010
Typology: terraced house
Target: single family house

Data collection:

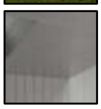
The restoration of this house is part of a wider project of revitalization of the disadvantaged neighbourhoods by renovating and then selling to private client to attract inhabitants in the area (ARC.2, SOC.2, SOC.3). The intervention creates a completely new building within the skeleton of the existing building (STR.1).
The front façade is totally painted black: masonry, frames and "windows" are covered with a shiny black oil while new offset glass windows pierce through this image suggesting a very different way of living (ARC.3, TEC.1).
Like in the façade, also in the interior the traces of the past remained visible in the outer brick walls that are left intact, to display the history of the building. Anyway, the new house has a completely different plan where small rooms run into one spatially contiguous entity, connected horizontally but also vertically (STR.1, STR.3, ARC.2, ARC.3).
The traditional layout of floors, stairs and walls blend together into a series of small wooden slats (TEC.1), sculptural elements composing the living spaces, causing a high degree of spatial abstraction (ARC.2).
In the lower part of the house a large workroom is placed connected to the 'roof tiles-bamboo garden’. The old roof tiles are removed in the upper part (re-used in the garden) and a new greenhouse is placed with a hot tub with a stunning view (TEC.1, TEC.2).
The disorientation continues with the entire side of the building, which is covered in artificial turf. The original lath has been reinserted into the ceilings (ARC.2, ARC.3, TEC.1).
In the house, five colours are used: black, white and three greyscales. An existing side wall is totally painted white. The traces of construction, including the old railings and pipes are all painted white. The other building wall is left untreated. The different faces of the object are painted in three greyscales. These shades are aligned to the space they enclose (ARC.3, TEC.1).

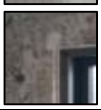
Summary:
STR.0) Structure > Radical strategy
ARC.0) Architecture > Radical strategy
SOC.0) Society > Medium strategy
FUN.0) Function > Heavy strategy
TEC.0) Technique > Medium strategy
CON.0) Construction > Heavy strategy

Material palette:



Shiny black oil

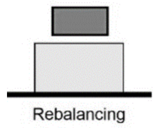

Artificial turf


Wooden slats


Original bricks

DATA SHEET N. 12


Action: volumetric/spatial



A fossil architecture that comes back to life.

General data:

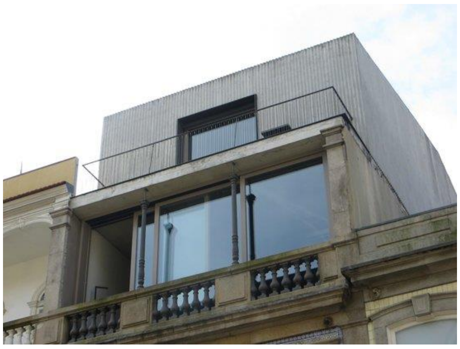
Project: Casa do Conto
Site: Porto, Portugal
Architect: Pedra Liquida
Client: Casa do Conto, Arts and residence
Construction: XIX century
Renovation: 2011
Typology: terraced house
Target: mixed

Data collection:

This House of Tales embodies the history of life and of the city in a new hotel conversion (ARC.1). The project strategy is centred on the restoration of the entire building, recovering its original architectural value (ARC.1, ARC.3).
Graved by various texts, in low relief, covering six separate rooms, these ceilings narrate the changes undergone by the concept of “house” and of this house in particular. The texts are created by different authors related to the city and its architecture and this solution marks the difference in personality of each space (ARC.1, ARC.2, ARC.3)
The building offers an innovative hotel concept providing a personalized style of residence for guests who wish to combine resting with the enjoyment of ultural offer, or for those who wish to create, display or even debate art working (FUN.1, FUN.2).
The new interventions are adapted to the architectural language already present in the house (ARC.3, TEC.1). The planned layout includes an entrance hall with vertical access to every floor of the building. In the the focal point of the building, a skylight was designed to capture light from the outside, and enable visual contact with the sky (ARC.1, TEC.2). The house's social areas are arranged throughout floors 0 and -1, with the upper floors reserved for the private rooms.

Summary:
STR.0) Structure > Light strategy
ARC.0) Architecture > Medium strategy
SOC.0) Society > Light strategy
FUN.0) Function > Heavy strategy
TEC.0) Technique > Medium strategy
CON.0) Construction > Unknown strategy

Material palette:



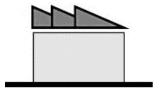


Granite stone


Concrete

DATA SHEET N. 13

Action: volumetric/spatial



Contrast

A “village” over the roof of a traditional row house.

General data:

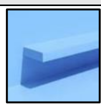
Project: Didden Village
Site: Rotterdam, Netherlands
Architect: MVRDV
Client: Didden’s family
Construction: end of the XIX century
Renovation: 2006
Typology: terraced house
Target: single family

Data collection:

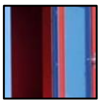
The project explores the idea of rooftop densification realizing the expansion of the Didden family’s house and atelier, a traditional row house of dark brick (ARC.1, ARC.2, ARC.3). In a dense urban context, the vertical dimension is the only possible direction of development and the large rectilinear roof surface of the existing house is the only place to create new usable surface (ARC.3, SOC.2, SOC.3).
The project of addition looks like a plastic model over the roof of the building, an architectural prototype showing the new design concept at the same time adding a novel character to the skyline of the city (ARC.1, ARC.2).
Bedrooms are organized in separate volumes, miniaturized houses surrounded by streets, squares, trees and shared facilities creating an overhead village, mimicking the same logics of an urban settlement (SOC.3, FUN.2).
A clear parapet encloses the intervention and presents windows, which frame views of the landscape at the same time granting the privacy of the family (ARC.2, SOC.3).
All the elements are shaped as elementary geometries, so the staircases are cylinders that pierce the older roof floor to connect the new volumes with the existing kitchen and living room (ARC.3, FUN.3).
Prefabricated beams bear a concrete structure (STR.1) with an outer coating in sky-blue polyurethane (ARC.3, TEC.1), which covers and uniforms every elements of the new addition granting a complete and durable waterproofing effect and long lasting colour effect (TEC.1, TEC.2, TEC.3, CON.1).
Warm colours, such as red and brown, are used in indoor spaces where prefabricated birch plywood panels covers the vertical surfaces (ARC.3, TEC.1, TEC.2, TEC.3, CON.1).
Prefabrication process, both for structural elements and finishing, allows to maintain minimal costs and anyway lower than using traditional systems or of the equivalent ground price for a building (CON.1, CON.2, CON.3).

Summary:
STR.0) Structure > Medium strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Light strategy
FUN.0) Function > Light strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Medium strategy

Material palette:



Prefabricated concrete with sky-blue waterproof polyurethane coating



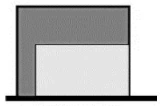
Red painting

Prefabricated birch plywood panels

Vegetation

DATA SHEET N. 14


Action: volumetric/spatial



Integration

An expansion that changes completely the visual balance of the building.

General data:

Project: Heliotrope over elevation
Site: Paris, France
Architect: Bang architects
Client: private
Construction: XX century
Renovation: 2010
Typology: terraced house
Target: single family

Data collection:

The existing building consists in a small two-storey construction located in a narrow courtyard, isolated visually and physically by the surrounding building almost 20 meters high (ARC.2, FUN.3).
The district is located in a suburban area rich in history (ARC.1), but the site is humid because of the presence of an underground aqueduct and it lack of natural daylight (SOC.3, TEC.3).
The four people family required more space but also a more liveable house, keeping into the constraint of the urban regulations, the low budget and above all, the lack of usable space (SOC.3, FUN.3, TEC.1, CON.2).
The access to the site is just 90 centimetres wide so the wood represented the best technological choice, being ecologic, light, easy to handle and to carry (CON.1, CON.2, CON.3).
The new expansion incorporates completely the existing building so that the new centre of gravity of the new house is located in the upper floors (ARC.2) where the timber frame (STR.1, TEC.1) is visible and allows the maximum amount of daylight (TEC.2).
Since the existing house is realized with a single layer of bricks 11 centimetres deep, it was necessary to create an additional structure composed by a series of timber columns “Douglas”, asymmetric on respect to the upper frame, which create a unitary language for the façade (STR.2, ARC.2).
The environmental approach is verified in the design of a compact volume with a good thermal insulation given by wooden wool and with no thermal bridges thanks to the diffuse use of wood (TEC.1, TEC.2, TEC.3).
The facades work as a shade during the summer while low emissive glasses and natural daylight helps further the energy performances (TEC.1, TEC.2, TEC.3).

Summary:
STR.0) Structure > Heavy strategy
ARC.0) Architecture > Radical strategy
SOC.0) Society > Heavy strategy
FUN.0) Function > Heavy strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Radical strategy

Material palette:



Laminated Douglas fir (untreated)

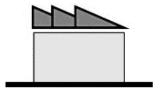

Wall structure and cladding in larch wood


Pine wood panels


Thermal break aluminium frame with double glazing low-emissivity glass

DATA SHEET N. 15


Action: volumetric/spatial



Contrast

A project for densification.

General data:

Project: Lude house
Site: Murcia, Spain
Architect: Grupo Aranea
Client: Juan Antonio Ludeña
Construction: -
Renovation: 2011
Typology: terraced house
Target: single family house

Data collection:

The client wanted to build an extension of his family house in the dense urban context of the city (ARC.1, SOC.2). The new house is a roof expansion which relates to its environment in a particular way: due to the density of the area it doesn't open directly to the nearby facades but looks along the narrow streets to see the landscape, the Burete mountains and the San Agustin Hill (ARC.2).
In spite of looking different to the other buildings of the neighbourhood, the house is as compact and introverted as them. On the other hand the project denies a conventional layout of the rooms creating unique, continuous and rich space on different levels with various heights and directions (ARC.2, ARC.3).
This space extends to the roof as a natural continuation of the interior life. It is a complex space full of light where many situations happen.

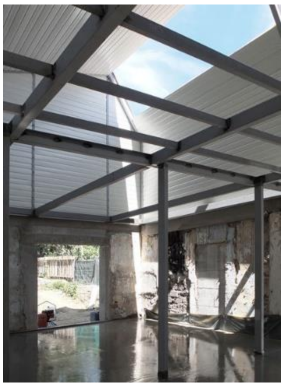
Summary:
STR.0) Structure > Light strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Medium strategy
FUN.0) Function > Unknown strategy
TEC.0) Technique > Light strategy
CON.0) Construction > Light strategy

Material palette:

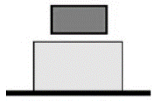

Polyurethane membrane

Natural stone

DATA SHEET N. 16



Action: volumetric/spatial



Rebalancing

A comparison between old and new.

General data:

Project: M03 house renovation
Site: Toulouse, France
Architect: BAS architects
Client: -
Construction: -
Renovation: 2013
Typology: terraced house
Target: single family

Data collection:

In the suburbs of the city, this construction reinterprets the characteristic typology of the streets (ARC.1) making a new comparison between the existing texture and a new addition, made entirely of a lightweight metal frame structure, tending towards abstraction (ARC.2, ARC.3).
The metal-clad addition replaces the building's damaged roof and sits on top of existing limewashed stone and brick walls, which echo the construction of other buildings on the street (ARC.1, TEC.1).
The project responded to planning regulations outlawing the demolition of the existing house by designing a vertical extension that will give its inhabitants an additional storey once the interior refurbishment is completed (STR.3).
Part of the history of this street, this whole existing masonry base with the new metal top construction is changing the types of living to the current issues of urban renewal and adaptation of old buildings to new ways of living.
The ground floor will contain an open plan living room and kitchen, with a separate area housing a bedroom, bathroom and storage space (FUN.1).
The form of the roof has been shaped to bring northern light inside the renovated dwelling, ensuring that the upper level of the building remains brightly and naturally lit (TEC.2).
The use of the strong but lightweight corrugated material reduces stresses on the lower storey and the extension allows the metal to not overload the existing foundations and walls (TEC.1, STR.1, STR.2, STR.3).
A new framework constructed inside the existing walls will support a first floor containing two bedrooms, a bathroom and a mezzanine office (STR.1, STR.2, STR.3, FUN.1).

Summary:
STR.0) Structure > Heavy strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Light strategy
FUN.0) Function > Light strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Light strategy

Material palette:

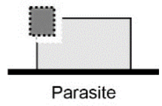
Stone and brick

Steel frame

Corrugated steel

DATA SHEET N. 17

Action: volumetric/spatial



A multifunctional timber box.

General data:

Project: Neo Leo
Site: Cologne, Germany
Architect: Luderwaldt
Client: -
Construction: -
Renovation: 2006
Typology: terraced house
Target: single family

Data collection:

A wooden box, a multifunctional living area, has been created by inserting a prefabricated element by crane into a roof extension of a Wilhelminian style family house (TEC.1, CON.1).
The precise slot-in construction comprising large format 56 mm plywood sheets functions on three levels as stairs, railings, room-divider, cupboards and shelving (FUN.1, FUN.3, TEC.1).
It structures the entire apartment as a bright orange sculptural element (ARC.3). The interplay between these newly defined core functional areas generates an interrelated vertical structure that opens out into a glassed studio on the top floor.
In construction terms the box hangs freely in space (STR.1). It rests on cams screwed onto the sides attached to newly inserted steel beams within the original building so that no additional load is placed on the wooden-beamed floors below (STR.1, STR.2, TEC.1).
The surface treatment for the wood all took place in the workshop before installation. All visible surfaces are treated with colourless oil and the stairwell cavity is lacquered in bright orange (TEC.1).
The vertical insertion of space and function effectively connects three floors of the house together into a family home (FUN.3). An affordable architectural solution in a residential area with a vital and mixed society (ARC.3, SOC.3).

Summary:
STR.0) Structure > Medium strategy
ARC.0) Architecture > Medium strategy
SOC.0) Society > Light strategy
FUN.0) Function > Heavy strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

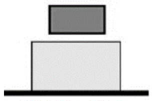
Material palette:

Prefabricated large format 56 mm plywood sheets treated with colourless oil

Prefabricated large format 56 mm plywood sheets lacquered in bright orange

DATA SHEET N. 18

Action: volumetric/spatial



Rebalancing

An expansion of the building using appropriate technologies.

General data:

Project: Over elevation in Rue Daumer
Site: Paris, France
Architect: Le Bihan Architectes
Client: private
Construction: 50s
Renovation: 2010
Typology: terraced house
Target: single family

Data collection:

The project involves an increment of two floors with a timber structure and an envelope in aluminium with different density in order to reduce the volume and the weight of the expansion (STR.1, TEC.1).
The envelope create a clear distinction from the existing building unifying all the parts of the addition (ARC.2, ARC.3).
The intervention created new spaces but also increased the value of the construction in terms of space, aesthetic, sustainability, ecology and energy performance (ARC.2, SOC.3, TEC.2, CON.1, CON.2)
Prefabrication of the structural elements and of the wooden panels allows a rapid implementation and easy construction process (STR.1, CON.1, CON.2, CON.3).

Summary:
STR.0) Structure > Medium strategy
ARC.0) Architecture > Medium strategy
SOC.0) Society > Unknown strategy
FUN.0) Function > Unknown strategy
TEC.0) Technique > Medium strategy
CON.0) Construction > Medium strategy

Material palette:

Aluminium grid panels with prefabricated structure

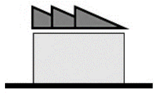
Wooden panels

Green roof

Vegetation and glass

DATA SHEET N. 19

Action: volumetric/spatial



Contrast

An expansion of the building using appropriate technologies.

General data:

Project: Over elevation in Rue Delbet
Site: Paris, France
Architect: Le Bihan Architectes
Client: El Mahmoud and Baudin
Construction: XIV century
Renovation: 2006
Typology: terraced house
Target: single family

Data collection:

An existing three-story building, with a façade Art Dèco, required an expansion on the rooftop.
The existing construction had some deficiencies in the foundation level and for this reason the only possible option was to add a light structure (STR.1, STR.2, TEC.1).
Other two stories are added, as a kind of attic composed by a deconstructed volume to recall the balance proposed by the existing façade at the same time recreating new entrances, new viewpoints and accesses for the natural light (ARC.2, SOC.3).
If the elevation presents a discontinuity in the geometry, the zinc-panelled coating is able to merge completely in the landscape of the city (ARC.2, ARC.3). The structure of the building is realized with timber panels glowed together, thermally insulated and then covered from the outside with zinc (STR.1, TEC.1).
The concept of the new construction is the enhancement of the performances of the building thanks to the proper design of the façade with the use of insulating materials and wide openings to favour the natural illumination (TEC.1, TEC.2, TEC.3).
The process is optimized to permit the family to stay in their house during the construction of the addition (CON.1, CON.2, CON.3).

Summary:
STR.0) Structure > Medium strategy
ARC.0) Architecture > Medium strategy
SOC.0) Society > Unknown strategy
FUN.0) Function > Unknown strategy
TEC.0) Technique > Medium strategy
CON.0) Construction > Medium strategy

Material palette:

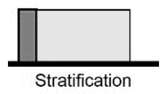
Insulation layer and zinc pannelled cladding

Glass

Glowed timber panels

DATA SHEET N. 20

Action: superficial/two-dimensional



Prefabricated timber for passive renovation.

General data:

Project: Passive renovation De Kroeven 505
Site: Roosendaal, Netherlands
Architect: DAT architecten
Client: Aramis Alleewonen
Construction: 1965
Renovation: 2010-2011
Typology: terraced house
Target: social housing

Data collection:

The district consists in 370 identical family houses that after forty years of use and only gradual improvements and normal maintenance needed an upgrading and a substantial redevelopment (TEC.3). The owner and the tenants of the social housing district both expressed the interest in an energy efficient renovation (SOC.2).
The process was planned in order to allow the tenant to stay in their houses during the whole construction and for this reason it was decided to use fast and nonintrusive techniques (CON.1).
The designers developed an approach based on prefabricated timber elements and implemented on 134 houses. Before the elements of the facades were mounted, gardens were partially cleaned and the external cavity leaf demolished (CON.1). Next, the perimeter was insulated and the foundation for the timber elements was adjusted (STR.2, TEC.1). After mounting the prefabricated elements, the facades were cladded with the natural slate tiles, the radiator system was completed, the ventilation ducts were installed, and final finishing works were done. The renovation process was completed with front gardens and the tree planting (TEC.1, TEC.2).
The process has been streamlined in order to allow the renovation of 4 houses per week. The elements for one house have been transported on one truckload, which travelled during the night and installed the next day so that tenants experienced only one day when there was no roof and no windows. The whole process of renovation from start to completion took only six weeks. (CON.1, CON.2, CON.3)
The original radiator system has been adjusted to the smaller heat demand while fresh air is provided by the ventilation unit to the habitable spaces and exhausted via toilet. To avoid discomfort at any time an additional heat loop is installed to post heat the ventilation air (TEC.2, TEC.3). Hot water is provided from the storage tank which is fed by solar thermal collectors, and the condensing gas boiler (TEC.2).
The process has proofed to be efficient and cost effective. The tenants were less disturbed by the renovation process and benefit by a lower heating bill, which in future is less sensitive to energy price increases.

Summary:
STR.0) Structure > Medium strategy
ARC.0) Architecture > Light strategy
SOC.0) Society > Unknown strategy
FUN.0) Function > Unknown strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Radical strategy

Material palette:

Timber frame element with cellulose insulation

Natural slate tiles

Prefabricated timber filled with insulation, covered with PVC with solar collectors

Thermally broken windows with triple glazing

DATA SHEET N. 21

Action: volumetric/spatial

Remodelling

Building urban caos.

General data:

Project: Peugeot blocks
Site: Béthoncourt, France
Architect: Lucien Kroll
Client: -
Construction: -
Renovation: 1995
Typology: terraced house
Target: single family

Data collection:

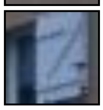
The intevention is a partial demolition of the buildings in order to avoid the complete demolition, avoiding stronger approaches (ARC.3).
The idea is to build against the modernism and the industrialization with their geometric rules in order to develop a more complex and various environment (ARC.2, ARC.3).
The main concept behind this approach is the study of a new relationship between the habitat and the inhabitant, with the awerness of the great margin of diversity, looking for the real sense of living (SOC.3).
The existing building is completely modified in its geometry and appearance, in order to create a not organized place, a urban caos, able to give a sense to the complex (ARC.3). The caos is the strategy to consider the necessity of all the different clients, being the participative design an obliged passage to arrive to a proper design (SOC.2).
The design of the building is defined also creating new relations between objects and people: streets and squares are places for relations but it is impossible to fix them to a geometric grid. A plan should be defined by the relationships without any preestablished order between the elements but with a relative order, or better a logic disorder which works because defined by the elements themselves (SOC.1, SOC.2, SOC.3).

Summary:
STR.0) Structure > Heavy strategy
ARC.0) Architecture > Radical strategy
SOC.0) Society > Heavy strategy
FUN.0) Function > Heavy strategy
TEC.0) Technique > Unknown strategy
CON.0) Construction > Unknown strategy

Material palette:

Tiles

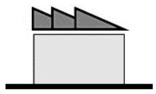
Painting



Wood

DATA SHEET N. 22

Action: volumetric/spatial



Contrast

An addition living in symbiosis with the existing building with a mutual advantage.

General data:

Project: Simbyont
Site: Merzig, Germany
Architect: FloSundK
Client: Patrick & Sabah Friedrich
Construction: 60s
Renovation: 2004
Typology: terraced house
Target: mixed

Data collection:

The house is located in the heart of a small town next to the old town hall and an idyllic little river (ARC.1). The young couple lived in an 80 m2 flat on the top floor of their tile-clad building which houses both family and their longstanding hairdressing business (FUN.2).
The objective of the project was to enlarge the daily area and to complete the roof structure with a roof garden and a winter garden (SOC.2, FUN.1). Because of the limited budget the architects decided to use the house as base and perched the new rooms on top (CON.1, CON.2).
The living room and the kitchen were combined demolishing (STR.1) the dividing wall creating a new space with a big lucernario, connected to the main building with a lightweight steel stair that is also a canal for the natural ventilation and daylight (FUN.3, TEC.1, TEC.2).
The new structure is realized in wood, with low cost prefabricated timber framed boxes (TEC.1, CON.1, CON.2). There is a symbiosis between the new two structures.
The two boxes, called the “living- box” and the “winter garden-box”, are intentionally not matching with the geometry and materials of the original structure, which is covered in light blue and cream-coloured tiles.
The green firewall (TEC.2) facing the neighbours’ property is instead a pre-cast concrete element (TEC.1), which was screwed onto the existing concrete-roof (CON.1).
Distinct materials reflect the different functions of the roof boxes: the “noble” living-box is covered with dark grey chipboard, whereas the “natural” winter-garden-box is covered in untreated zinc-plates that will take on their own natural patina with age (ARC.3, TEC.1).

Summary:
STR.0) Structure > Medium strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Light strategy
FUN.0) Function > Medium strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

Material palette:

Precast concrete with green painting

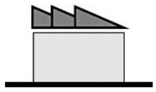
Dark grey chipboard on prefabricated timber box

Untreated zinc-plates and glass on prefabricated timber box

Vegetation

DATA SHEET N. 23

Action: volumetric/spatial



Contrast

An addition to uniform again the view of the street.

General data:

Project: St. Johanns-Platz 25, 4056
Site: Basel, Switzerland
Architect: Anarchitekton Wenger
Client: Barbara Lenherr and Andreas Wenger
Construction: 1879
Renovation: 2003
Typology: terraced house
Target: single family

Data collection:

The house is the last remain of a homogenous street formed by three-story buildings (ARC.1). Now the street is occupied by five-story houses creating a volumetric unbalance (ARC.2).
To soften the difference the renovation project designs the completion of the roof structure adding a new volume (ARC.3).
In this way it is possible to maintain the elements of tradition of this area of city but with new modern elements. The vicinity of the surrounding modern buildings give the pretest to create a new interaction between the past and the present intermediating the different languages.

Summary:
STR.0) Structure > Medium strategy
ARC.0) Architecture > Medium strategy
SOC.0) Society > Unknown strategy
FUN.0) Function > Unknown strategy
TEC.0) Technique > Light strategy
CON.0) Construction > Medium strategy

Material palette:

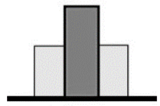
Timber panels

Glass

Covering panels

DATA SHEET N. 24

Action: volumetric/spatial



Filling

A mediation that is also a statement of modernity.

General data:

Project: Tayson House in “Little Germany”
Site: Bradford, Great Britain
Architect: Kraus &Schoenberg
Client: -
Construction: 1870
Renovation: 2008
Typology: terraced house
Target: single family

Data collection:

The formation of the district took place in various stages and this can be detected in the different sizes of the warehouses (ARC.1). Starting with two to three storey buildings in the early 1830s, the trend changed towards grander structures in the late 1850s (ARC.1).
Tayson House was built around 1870 with four floors but the adjacent building has just two floors. In order to mediate between the two historical buildings, a new infill was created (ARC.1, ARC.2, ARC.3).
The new extension is hung from a steel frame creating a minimal interface with the existing buildings (STR.1, STR.2, STR.3, TEC.1, CON.1).
By creating its own architectural language the glass, galvanised steel and timber structure can be seen as a separate entity (ARC.2, ARC.3, TEC.1).
This allows a continuation of the industrial character of Little Germany and helps regenerating the area (ARC.1).

Summary:
STR.0) Structure > Medium strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Unknown strategy
FUN.0) Function > Unknown strategy
TEC.0) Technique > Medium strategy
CON.0) Construction > Medium strategy

Material palette:

Timber frame

Galvanized steel

Glass

Timber panels

DATA SHEET N. 25

Action: volumetric/spatial

Stratification

Adding timber loggias on an existing façade.

General data:

Project: Bondy Loggias
Site: Paris, France
Architect: Laurent Pillaud
Client: Semidep
Construction: -
Renovation: 2009
Typology: row house
Target: families

Data collection:

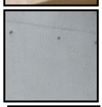
The intervention renovates the existing facade with multi-purpose wooden loggias.
The structure of the loggias is made of glued spruce panels and the cladding is in larch with a waterproofing coating with double glasses (STR.1, TEC.1, TEC.2). Aging the wood colour will become silver (ARC.3, TEC.3).
Each loggia is 6 sqm and it's singularly prefabricated and adjusted one by one on open concrete foundations, so it is not hanging from the building but the façade has been only rectified (STR.1, TEC.1, CON.1). In this way the installation requires just three persons and a crane and the whole construction process lasts only two months (CON.1, CON.2, CON.3).
The loggias offer a new space and a new value to the whole building, changing the image of the district without requiring demolitions (ARC.1, ARC.2).
Some inhabitants could use the additional space as a winter garden or an expansion for the living area (FUN.1).
Another benefit will be the reduction of the noises coming from the highway located near by with a general improvement of the comfort for the users (TEC.2).

Summary:
STR.0) Structure > Heavy strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Light strategy
FUN.0) Function > Medium strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Radical strategy

Material palette:

Glued spruce panels

Larch with a waterproofing coating



Open concrete foundations

Double glasses

DATA SHEET N. 26


Action: superficial/two-dimensional

Stratification

A new performing envelope.

General data:

Project: Falconer Rehabilitation
Site: Gonesse, France
Architect: Atelier Jens Freiberg
Client: Osica
Construction: 1965
Renovation: 2009
Typology: row house
Target: mixed

Data collection:

The city is located close to the airport and it is crossed by the railway (ARC.1).
The complex is composed by 2500 dwellings, built with the historical technique of the concrete tunnel formwor, visible from the outside and problematic for thermal bridging (TEC.2, TEC.3). The façade was in wooden panels and light bricks (TEC.1, TEC.2).
The existing frame was covered with an insulation layer and the existing facades have been substituted (TEC.2).
A new external shell with a wooden frame highly insulated cover the entire structure with acoustic insulating glazing windows with low emissivity (TEC.1, TEC.2, TEC.3).
The new panels are prefabricated and assembled with metallic brackets (TEC.2, CON.1) in just one day to let the inhabitants staying in the apartments during the entire construction process (CON.3).
Also the roof terrace has been refurbished with an insulation layer in order to avoid thermal dispersions (TEC.2, TEC.3).
A big challenge was to adequate the new wooden boxes to the various horizontal and vertical alignments (TEC.3, CON.1).

Summary:
STR.0) Structure > Light strategy
ARC.0) Architecture > Medium strategy
SOC.0) Society > Unknown strategy
FUN.0) Function > Unknown strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

Material palette:

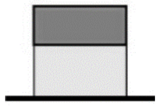


Acoustic insulating glazing with low emissivity


Metal brackets

Highly insulated wooden panels

Action: volumetric/spatial



A passive house on the roof.

General data:

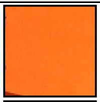
Project: Fordsiedlung der LEG
Site: Koln, Germany
Architect: Archplan GBR arkitekten
Client: -
Construction: 50s
Renovation: 2010
Typology: row house
Target: mixed

Data collection:

The existing apartments were characterized by small plans and high-energy consumption (TEC.2). The intervention wants to provide better energy performances and 81 new bigger dwellings in a rooftop extension (SOC.2, TEC.2). Due to the orientation north-south of the units it was necessary to build new pitched roofs over the expansion in order to locate solar panels all over the surface decreasing dramatically the energy consumption (TEC.2).
All the existing apartments have been restored with new bathrooms, kitchen and spacious balconies; the envelope has been provided by an insulation layer and new windows while all the apartments have new ventilation systems (SOC.3, FUN.1, TEC.2, TEC.3).
The new expansion is instead completely built following the principles of the passive house (TEC.2).
The existing structure was not able to carry all the new loads requiring an additional structure (STR.1, STR.2, STR.3).
The walls are prefabricated timber panels with integrate insulation and dry construction process (TEC.1, CON.1).
The entire district has a completely new energy performance in line with the new regulations (TEC.2).

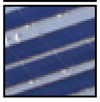
Summary:
STR.0) Structure > Heavy strategy
ARC.0) Architecture > Light strategy
SOC.0) Society > Light strategy
FUN.0) Function > Medium strategy
TEC.0) Technique > Radical strategy
CON.0) Construction > Heavy strategy

Material palette:



Prefabricated timber panels with integrate insulation and orange painting

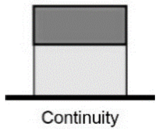
Metal structure



Solar panels

DATA SHEET N. 28

Action: volumetric/spatial



New spaces and performances wrapped in a modern look.

General data:

Project: La Golette
Site: Meyrin, Switzerland
Architect: Atlante SA
Client: Swiss & Global Asset Management
Construction: 60s
Renovation: 2010-2011
Typology: row house
Target: families

Data collection:

The new owner of the four-storeys building decided to extend the building for its entire length to enhance its value and the consequent economic income (CON.1, CON.2). The existing nine staircases connect the thirty-six new apartments on two levels with the existing storeys, providing greater and more differentiated housing provision (FUN.3, SOC.2).
The operation had to be finalized in just twelve months, with challenges on the technical, social and environmental points of view (CON.3). For this reason it was decided to use light technological solutions, faster and easier to assemble allowing to maintain the building in use during the construction process avoiding nuisances as much as possible (SOC.3, TEC.1, TEC.2, CON.1, CON.2, CON.3).
The over-elevation has a steel structure, with mixed wood and concrete floor slabs, which confer good performances in terms of weight and acoustic insulation (STR.1, TEC.1, TEC.2). For the façade it was used a prefabricate technology in timber, thermally insulated and able to reproduce the architectural pattern of the existing building (ARC.1, TEC.1, TEC.2).
Construction times have been limited thanks also to the use of prefabricated cabins for the toilettes (CON.1, CON.3).
A green roof helps to accumulate the rainwater favouring the thermal performance in summer while the heating system was connected to the existing network, which was simply implemented for the new capacity (TEC.2, TEC.3).
An important element of the design is the addition of lateral blind facades completely covered with photovoltaic panels, which provide green energy and at the same time confer a new modern look (ARC.2, ARC.3, TEC.1, TEC.2).
The intervention made the building compatible with the anti-seismic regulations of the country (STR.2, STR.3).

Summary:
STR.0) Structure > Heavy strategy
ARC.0) Architecture > Light strategy
SOC.0) Society > Light strategy
FUN.0) Function > Light strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

Material palette:

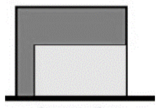
Prefabricated timber units with insulation

Concrete and wood slabs with steel structure

Photovoiltaic panels

DATA SHEET N. 29

Action: volumetric/spatial



A symbol of sound performance and social security.

General data:

Project: Leeuw van Vlaanderen
Site: Amsterdam, Netherlands
Architect: Heren 5
Client: Far West
Construction: 1960
Renovation: 2005
Typology: row house
Target: social housing

Data collection:

The building presented seventy-two dwellings and it is located around three meters far from the guardrail of the highway. The construction works as a noise barrier but is is also an important symbol for urban regeneration working as an input for virtuous processes (ARC.1, SOC.3, TEC.2).
Two more floors and twenty-four new apartments have been added on the roof of the building, exploiting the concrete frame structure, with the introduction of a second soundproof curtain wall facing the highway (STR.1, TEC.2). Between the new facade and the previous one there will be open galleries and a new elevator to improve the common areas and the accessibility to the apartments but also natural ventilation (SOC.3, FUN.3). The new sound barrier and the galleries present a steel structure and wood floors; the foundation of the galleries and elevators are on steel piles (STR.1, STR.2).
Also the new two floors have a steel structure, chosen for the light weight and the structural qualities since the concrete roof of the building was not able to carry additional loads. There are sixty centimeters between the former roof and the new floor, which are used as technical room (STR.1, STR.2, TEC.1, CON.1).
The requalification process provided a new social quality thank also to the higher social security provided y a greater amount of users (SOC.1, SOC.2, SOC.3).

Summary:
STR.0) Structure > Heavy strategy
ARC.0) Architecture > Light strategy
SOC.0) Society > Heavy strategy
FUN.0) Function > Heavy strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

Material palette:

Soundproof curtain

Steel structure

DATA SHEET N. 30


Action: volumetric/spatial


Stratification

An holistic approach to densification.

General data:

Project: Minimum impact house
Site: Frankfurt, Germany
Architect: JDS Architects
Client: -
Construction: -
Renovation: 2008
Typology: row house
Target: single family

Data collection:

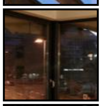
Minimum-Impact-House is a holistic approach for the reduction of the overall-impact of residential housing by creating a new type of residential house by densifying the city centre (SOC.2).
In the design project, a prototype mini-house has been developed to explore the potential of so far uninhabitable urban niches.
A triangular site of only 29 sqm was chosen to build a Mini-house in size comparable to a family house of 150 sqm. This strategy avoids the further use of land and the need of building of new infrastructure like streets and public buildings (ARC.2, SOC.3).
The city centre is denser an environment so that the inhabitants will not to travel so often to work, shopping, education, or cultural events.
In a research project, the prototype was compared to a typical suburban house.
A life-cycle-analysis quantified the amounts of energy, material, and investment for the construction, and consumed during an estimated life span of the buildings of 50 years (TEC.1, TEC.2, TEC.3, CON.1, CON.2).
The analysis was also used as a design-tool for optimising the prototype in terms of energy-consumption, construction, and materials (TEC.1, TEC.2, TEC.3, CON.1, CON.2).
For the building construction renewable resources, mainly timbre, had been used which reduces the energy content and emissions (TEC.1, TEC.2).

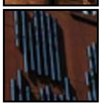
Summary:
STR.0) Structure > Medium strategy
ARC.0) Architecture > Medium strategy
SOC.0) Society > Heavy strategy
FUN.0) Function > Light strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

Material palette:



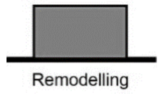
Wooden framed structure


Glass


Wooden cladding

DATA SHEET N. 31


Action: volumetric/spatial



The cruise ship in the city

General data:

Project: Republic housing complex
Site: Lorient, France
Architect: Castro Denissof Associates
Client: Lorient Habitat (public)
Construction: 1988
Renovation: 2003
Typology: housing block
Target: low-income dwellers

Data collection:

The project contributes to the diversification of the economy of the city suffering from the decline of the activities connected with the sea and the port (ARC.1, ARC.2, SOC.3, FUN.2).
The programme comprehends the rehabilitation and redevelopment of a 120-units low-income housing complex into a 99-units residence, and construction of three new buildings (55 units), a public plaza, and a park (ARC.2, ARC.3, SOC.3, FUN.2).
The urban placement or the main block – orthogonal to the other buildings – granted it a peculiar status. The redesign creates a ship, with its inner bow director towards the sea (ARC.2).
To obtain this formal result it was necessary to cut the upper edge of the former building in different stages creating in the meanwhile completely new floor plans, adding multiple parts. The new façade aims at breaking the monotony of the former housing block (ARC.2, ARC.3).
The building soon became iconic for the city and revitalized the area completely so that thereafter a new residence for homebuyers, the first of the area, appeared in this traditionally low-income social housing district (ARC.2, ARC.3, SOC.1, SOC.2, SOC.3, FUN.2).

Summary:
STR.0) Structure > Heavy strategy
ARC.0) Architecture > Radical strategy
SOC.0) Society > Heavy strategy
FUN.0) Function > Heavy strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Radical strategy

Material palette:

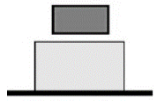


White finishing


Glass

DATA SHEET N. 32

Action: volumetric/spatial



Rebalancing

Wood in the sky, a link between the sky and the city.

General data:

Project: Rue Daubin 26-27-29
Site: Genève, Switzerland
Architect: Group 8
Client: represented by Georges Thaler
Construction: 70s
Renovation: 2011
Typology: row house
Target: families

Data collection:

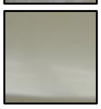
The building falls under the “Law on raised buildings” which recognizes to the district the possibility to increase the height of the buildings of two additional floors to create new housing provision (SOC.2, SOC.3).
This project provided an extension of the existing penthouse, which has been incorporated in a new wooden element (TEC.1). The addition is clearly recognizable but at the same time it presents some merging elements with the facade of the existing building, such as the same vertical lines and the same colour palette (ARC.3). This allows maintaining a unified perception of the upper floors (ARC.3).
The elevation is made entirely with wood, with the only exception of the common walls, made by cement blocks (STR.1, TEC.1). The precast panels of the existing penthouse have been covered with perforated wood cladding, which extend the elevation of its facade (STR.1, ARC.3, TEC.1, TEC.3).
The main challenge of this project was the extension of the three staircases maintaining the building in use for the entire duration of the construction process, moreover in a dense urban area (STR.1, STR.2, STR.3, FUN.3, CON.2, CON.3). Organization, communication and collaboration between all the stakeholders have been the key features for a successful operation (SOC.1, CON.1). On the other hand, a main characteristic of the building is the favourable and strategic location, which grants great views of the tows and the lake fountain (ARC.2).
The new loggias are designed to create an irregular skyline and they work as frames to ensure the privacy of the external spaces while at same time giving great views of the distant landscape (ARC.2, SOC.1, SOC.3).
From any of the staircases it is possible to reach two apartments, for a total of six, of four or six rooms (ARC.3, FUN.3). In this way any apartment can exploit a frontal and a rear views, with great advantages for the natural ventilation (ARC.3, SOC.3, TEC.2). Also, bedrooms are located on the courtyard side and the living areas facing Daubin street side, benefiting of the best orientation (SOC.3, TEC.2).
The new element grants also renewed energy performances, thanks to the high performance of the insulation, which limits the heat loss through the roof (TEC.2, TEC.3). Internal finishing accounts of parquet on the floor and smooth plaster on the ceiling and walls of the living areas (TEC.1).

Summary:
STR.0) Structure > Light strategy
ARC.0) Architecture > Light strategy
SOC.0) Society > Light strategy
FUN.0) Function > Light strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

Material palette:

Perforated wood cladding on wooden structure

Parquet



Smooth plaster

Glass

DATA SHEET N. 33	
 	**Action: volumetric/spatial**  Stratification — The revitalization of a degraded area. **General data:** Project: Square Vitruve Site: Charonne, France Architect: Atelier Du Pont Client: France habitation Construction: 70s-80s Renovation: 2013 Typology: row house Target: social housing

Data collection:

The building was erected on a concrete slab, virtually inaccessible, totally without vegetation and shapeless (ARC.1, ARC.2).

With the construction of the tramway on the nearby boulevard, it was necessary to rehabilitate this seriously degraded building containing 56 social housing units (SOC.3, FUN.3, TEC.3).

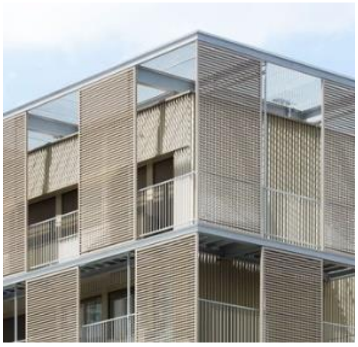
This intervention on the building's shell has been conducted in constant dialogue with the city's council and inhabitants in line with ambitious specifications (SOC.2).

Basing its analysis on sun studies to assess the impact of the nearby high-rise buildings the architects suggested adding balconies wherever this made sense (TEC.2).

This was a simple idea that was hard to put into practice because the site cannot be accessed by eavy plant, yet provided the apartments with outdoor areas and completely remodelled the architecture of the façades (FUN.1, CON.1). This new skin was installed without putting machinery on the concrete slab and using no cranes or pods (CON.1). The balconies are suspended from the roof, and all the materials and technical solutions have been designed to avoid overloading the existing structure and disrupting residents' daily life (STR.1, STR.2, STR.3, CON.1).

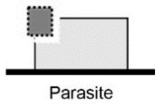
Summary:
STR.0) Structure > Heavy strategy
ARC.0) Architecture > Radical strategy
SOC.0) Society > Heavy strategy
FUN.0) Function > Medium strategy
TEC.0) Technique > Medium strategy
CON.0) Construction > Heavy strategy

Material palette:

 		Steel structure
		Outer cladding panel
		Inner cladding

DATA SHEET N. 34


Action: volumetric/spatial



New volumes are inserted into the existing building to create new spaces and atmospheres.

General data:

Project: Stadthaus Dreiheiligen
Site: Innsbruck, Austria
Architect: Daniel Fuegenshuh
Client: private
Construction: -
Renovation: 2007
Typology: row house
Target: apartments

Data collection:

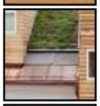
This project is signed by a participatory process in the most virtuous sense, with the overlapping of the desires of the client with the visions of the designers (SOC.1). Unhappy with the configuration of the former dwelling, the client approached the architect with a set of ideas mostly regarding the addition of extra airy spaces.
An expansion is realized exploiting the existing perimeter brickwork walls and the construction of a new ventilated roof in cross-laminated timber and wood wool insulation (STR.1, TEC.1, TEC.2, CON.1).
The expansion is realized with the insertion of two volumes in natural wood at different level of the roof (ARC.2, TEC.1) creating a completely new internal and external dimension (ARC.3, FUN.3).
The living area in now a double-height space with a great atmosphere and the contraposition of the new timber boxed with the original components, left almost unmodified such as the white perimeter walls that are re-plastered in adobe to increase thermal properties and contrast with the reflective black floors (TEC.1, TEC.2, TEC.3).
A minimalist staircase connects the ground floor to the newly added mezzanines without imposing heavily into the living room, and eventually lead to the newly inhabited attic which is transformed into a buffer space before reaching the large rooftop terrace (FUN.1, FUN.3). From the outside the timber boxes protrude from the original façade.

Summary:
STR.0) Structure > Heavy strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Medium strategy
FUN.0) Function > Medium strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Light strategy

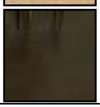
Material palette:



Cross laminated timber with wood wool insulation

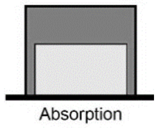

Green and copper roof


Glass


Reflective black floor

DATA SHEET N. 35

Action: volumetric/spatial



An outer cage to expand the building.

General data:

Project: Surefit
Site: Florence, Italy
Architect: Ipostudio
Client: public
Construction: 80s
Renovation: 2008
Typology: point house
Target: social housing

Data collection:

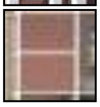
The project is part of a wider study concerning the social housing refurbishment throughout rooftop expansion, technologically and financially viable (TEC.2, CON.1, CON.2).The main objective was to develop an innovative approach and a model or guidelines for broader application of the solution in Europe.
In this case, the case study investigates the use of an outer structural cage in order to add new apartments and expand the existing ones (ARC.2, FUN.1). The intervention acts strongly on the envelope of the building modifying completely its appearance and perception (ARC.2, ARC.3) and also its performances (TEC.2).
The building owned by the city is a line block of four floors with thirty-three dwellings. The design is based on passive construction techniques, which are also prefabricated and flexible for the expansion and the creation of other nine apartments (TEC.1, TEC.2, CON.1).
The seismic condition of the area required a strategy of over-elevation based on an independent structural system that does not add any additional loads on the existing building (STR.1, STR.2, STR.3).
The structural frame presents a series of components for the façade, in order to implement the energy performance of the building –shading systems, solar and photovoltaic panels – (TEC.2) and houses new spaces and facilities for the existing dwellings (SOC.2, SOC.3, FUN.1).
The technical and technological choices allowed fast and cheap construction process, allowing the dwellers to stay in their apartments during the entire operation (CON.1, CON.2, CON.3).

Summary:
STR.0) Structure > Radical strategy
ARC.0) Architecture > Radical strategy
SOC.0) Society > Radical strategy
FUN.0) Function > Radical strategy
TEC.0) Technique > Radical strategy
CON.0) Construction > Radical strategy

Material palette:

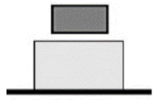

Steel with white finishing


Metallic sunshades


Prefabricated box

DATA SHEET N. 36

Action: volumetric/spatial



Rebalancing

The character of post-war architecture reinterpreted as a light renovation.

General data:

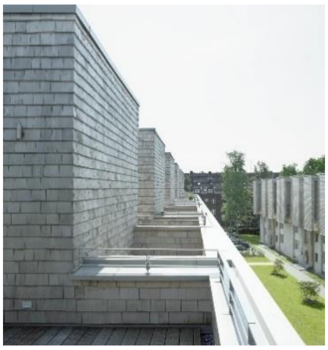
Project: Treehouse Bebelalle
Site: Hamburg, Germany
Architect: Blauraum
Client: Robert Vogel GmbH & Co. KG
Construction: 1959
Renovation: 2010
Typology: row house
Target: elderly people and young families

Data collection:

The building complex, at the edge of the city, is constituted by housing blocks with a shared green area (SOC.3). The renovation of the existing complex does not want to hide the historical origin of the settlements and its character so it operates with an addition of upper stories for energy upgrading and to double the usable area in order to densify the district (ARC.1, ARC.3, SOC.2). On the upper floors bigger apartments for young family are located creating a social mixing in the district, now occupied mostly by elderly people (FUN.2).
The new addition is realized in wood, in the form of rough, split cedar shingles in a way that the lightweight is declared also externally with a clear distinction with the lower floors and recolling the natural surrounding environment (treehouse) (ARC.3, TEC.1). The prefabricated timber panels and all the components are preduced in the factory and then assembled on site (CON.1).
The existing façades, of artificial yellow clinker and turquoise tiling as balcony cladding, were given an external layer of insulation and clad in a new layer of exposed hand-molded brickwork with a new shadowing (TEC.1, TEC.2).
The majority of the altogether 47 new units are configured as maisonette types. All of the apartments enjoy spacious roof terraces, and the maisonette apartments have loggias as well (ARC.3).
The decision for the addition of new upper stories by means of lightweight construction also featured the advantage of a relatively compressed construction schedule, and hence minimal noise and disturbance for residents of the existing units (CON.1, CON.3).The existing buildings are made of cheap materials with the maximization of the loads on the structure; for this reason the new addition was constituted with light materials but anyway required some implementation of the foundation system to bear the new loads (STR.1, STR.2, STR.3, TEC.1, TEC.2).
The design phase lasted one year while the construction just 3 months thanks to the high rate of prefabrication of the components (CON.3).

Summary:
STR.0) Structure > Heavy strategy
ARC.0) Architecture > Medium strategy
SOC.0) Society > Medium strategy
FUN.0) Function > Light strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

Material palette:



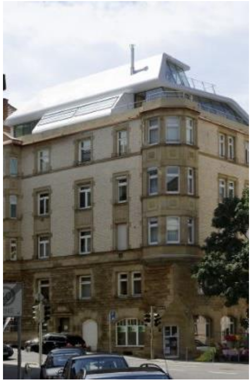
Rough, split cedar shingles covered by insulation and hand-molded brickwork

White painting

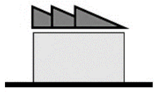
Rough, split cedar shingles

Vegetation

DATA SHEET N. 37

Action: volumetric/spatial


Contrast

An UFO landed on a building.

General data:

Project: UFO
Site: Stuttgart, Germany
Architect: Florian Danner
Client: Florian Danner
Construction: 1900s
Renovation: 2008-2009
Typology: row house
Target: owner occupied

Data collection:

The expansion is a futuristic and spectacular building of two floors on the roof of an historical building of the centre with a panoramic view of the city (ARC.1, ARC.2).
A provisional and obsolescent roof built after the second world war, which needed to be substituted, characterized the building. Since the former owner did not have enough money for this operation the space was sold to the architect for a symbolic price so that he could build there his own house (CON.2).
Despite the limits imposed because of the historical quality of the building and its localisation, at the end a visionary design was chosen, now become one of the symbol of the city (ARC.1, ARC.2, ARC.3).
A flat roof is deformed into a fluid surface to compose the whole structure of the building (STR.1, ARC.3).
Inside the building the architect decided to use sprayed white painting on the timber panels as the main colour for his loft, in order to not distract from the panorama of the city (ARC.3).
The structure with S shape is a modern timber-steel construction, prefabricated and then assembled on site (CON.3) with an insulation layer and a metal cladding (STR.1, TEC.1, CON.1). The other facades are completely of glass (ARC.3, TEC.1). The structure creates also wide external terraces and two different floors (FUN.1).
The lower floor has a spacious living room integrated with a kitchen and a working area; a lightweight steel stair connects the bedrooms and the bathroom (FUN.1, FUN.3).
The house collects solar energy and presents passive ventilation in this way the energy consumption are reduced of two third, with a great benefit also for the lower apartments (TEC.2).

Summary:
STR.0) Structure > Medium strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Unknown strategy
FUN.0) Function > Light strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

Material palette:



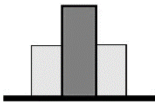
Glass


Timber-steel prefabricated structure with insulation and metal cladding


Timber panels with sprayed white painting

DATA SHEET N. 38


Action: volumetric/spatial



Filling

A connection between two old buildings.

General data:

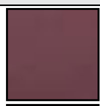
Project: Zwinglistrasse 9 and 15
Site: Zurich, Switzerland
Architect: Viriden + Partner AG
Client: -
Construction: 1881
Renovation: 2003
Typology: row house
Target: owner occupied

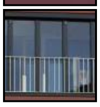
Data collection:

The two buildings are among the oldest in the neighborough (ARC.1). Between them, there was a gap of about 4 meters. The architects closed this gap by creating a structure which joins the two buildings at the level of the upper storeys and leaves open the access route to the courtyard behind the buildings (ARC.1, ARC.2). In doing this, they respected the constraints of the preservation order, under which the character of the street was to be maintained, and aligned the façade of the new structure with that of the neighboring buildings (ARC.1, ARC.2).
On the courtyard side, however, the new structure projects and acts as the connecting element between the two buildings. Although it fits into the courtyard harmoniously, this new structure is clearly recognizable as a modern element (ARC.2, ARC.3).
It allowed the architects to add a loggia or extend the living area of the flats on the upper floors (FUN.1).
The insulation layers are thick: in the old buildings, 16 centimeters on the street façade and 20 centimeters on the courtyard façade and on the side walls of the access area; in the new structure, 24 centimeters on the walls and 28 centimeters on the roof of the access area (TEC.1, TEC.2). At No.9, the attic floor was demolished and replaced with a prefabricated element (STR.1, STR.3, TEC.1); the insulation here is rock wool (36 centimeters). Next door, at No.15, it was possible to keep the original roof, which was then renovated and fitted with 32-centimetre cellulose fiber insulation (STR.1, TEC.3).
Solar collectors measuring a total of 40 square meters and a gas boiler produce the electricity for the heating, which, here too, is distributed via a controlled ventilation system and supported by wood-burning storage heaters if required (TEC.2).
The buildings offer a very respectable level of comfort. The interior fittings and design of the owner-occupied flats is of a high standard, the inside air temperature is good, and the air always remains fresh even when the windows are kept closed (TEC.2).
The triple glazing has the added advantage of providing effective sound insulation (TEC.2).

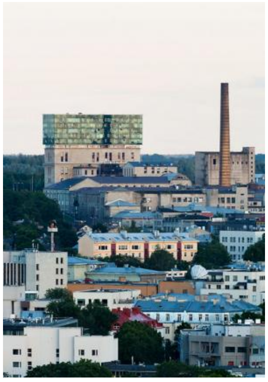
Summary:
STR.0) Structure > Heavy strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Light strategy
FUN.0) Function > Medium strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

Material palette:

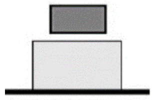


Prefabricated timber with insulation


Triple glazing glass

DATA SHEET N. 39




Action: volumetric/spatial



A symbol of the economic boom.

General data:

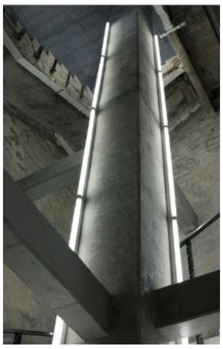
Project: Fahle House
Site: Tallinn, Estonia
Architect: KOKO architects
Client: Koger & Partners
Construction: 1926
Renovation: 2007
Typology: tower house
Target: mixed

Data collection:

The renovation project is the result of the recent economic boom in the country. The building was architecturally ambitious, controversial concerning the heritage protection and risky from a real estate development point of view (ARC.1, ARC.3).
The building is at one of the main entrances to the city and it is part of the complex of a former cellulose and paper factory.
The new building complex comphrends several service and business functions, from beauty salons to a restaurant while the main residential function is located inside the rooftop expansion (SOC.2, SOC.3, FUN.1, FUN.2, FUN.3).
The interior of the plant had been destroyed by the time reconstruction started and this made it possible to reorganize the internal layout and room division (STR.1, STR.2, STR.3, CON.1). Offices and service spaces are mainly located in the historical rooms of the plant. Different sized apartments are located inside the new section with a glass facade. The new section is supported by reinforced concrete beams, which have been hidden between the walls of the boiler house and reach down into the subsoil (STR.1).
The architects tried to preserve and display the historic interior details and the wall and floor surfaces where possible (ARC.1, ARC.3).

Summary:
STR.0) Structure > Heavy strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Heavy strategy
FUN.0) Function > Heavy strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

Material palette:

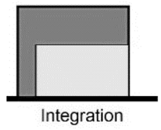

Limestone walls


Multi-coloured glass


Reinforced concrete beams

DATA SHEET N. 40

Action: volumetric/spatial



Keeping the elements of value in an inappropriate building.

General data:

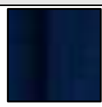
Project: La Chesnaie
Site: Saint-Nazaire, France
Architect: Lacaton & Vassal
Client: Silène
Construction: 70s
Renovation: 2014
Typology: tower house
Target: apartments

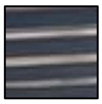
Data collection:

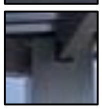
The building with forty apartments is part of an estate built in a period of massive development of housing in an optimistic view (ARC.1).
In more recent years the complex lost all its attractiveness among the inhabitants so that it was decided to demolish the building to rebuild new constructions (ARC.2).
However the final approach is more respectful of the existing environment and able to distinguish the elements of value and the potentialities - the solid and well preserved construction, the modernity, the privileged view points, the proximity to the city centre and the connections, the inhabitants and their management and participation, the green spaces and the trees (ARC.2, ARC.3).
The intervention operates a transformation with an expansion and in parallel a densification with new forty apartments as a long-term strategy: this approach is much more cost effective than the demolition and reconstruction (ARC.3, SOC.2). The existing facades with small windows are removed and replaced by large transparent openings, so that the inhabitants would profit of the exceptional view (ARC.3).
The project provides bigger apartments and the existing ones increase their surface of 33 sqm through the addition of a winter garden and a balcony without any major structural works affecting the organization of the building (ARC.3, FUN.1).
The bathrooms are relocated and in the former spaces there are storage rooms, while the expansions are occupied by additional bedrooms.
The climate control device, two meters wide, is composed by moveable transparent panels with fabric screens that serves as winter garden (TEC.2).The newly constructed apartments, backing onto the existing high rise, also have a generous amount of space, with winter gardens and balconies.
The structure is designed with prefabricated elements so that the inhabitants stayed in the apartments during the construction works (STR.1, TEC.1, CON.1).

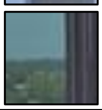
Summary:
STR.0) Structure > Medium strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Light strategy
FUN.0) Function > Medium strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

Material palette:


Textile


Metal


Steel


Glass

DATA SHEET N. 41

Action: volumetric/spatial

Stratification

An exemplary lesson of the benefits of retrofit.

General data:

Project: Le Bois le Prêtre
Site: Paris, France
Architect: Druot, Lacaton & Vassal
Client: Paris habitat
Construction: 1962
Renovation: 2011
Typology: tower house
Target: mixed

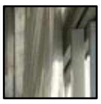
Data collection:

The tower includes sixteen floors with a total of ninty-six apartments.
The demolition, firstly envisaged, has been avoided and a project of transformation decided with a generous extension of the apartments (ARC.3, SOC.2, SOC.3).
New floors, built as a self-supporting structure (STR.1), are added on the periphery of the existing building at every floor, to extend the living rooms, create closable terraces and balconies (FUN.1).
The existing facades with small windows have been removed and replaced by large transparent openings, so that the inhabitants will profit of the exceptional (ARC.2, TEC.1).
The entrance hall have been refurbished becoming a free and transparent space, entrance also of a new garden created on the back of the building. Rooms for collective activities have been established on the sides of the hall (FUN.1). Two lifts improve the access to the apartments (FUN.3).
The structure is designed with prefabricated elements so that the inhabitants stayed in the apartments during the construction works (STR.1, TEC.1, CON.1).
A facade of corrugated aluminium clads the new exterior of the tower, interspersed with large windows and glazed balconies. Floor-to-ceiling glass separates the apartments from the new terraces to let more natural light into each residence (TEC.1, TEC.2).
The new organisation of surfaces and the precise technical improvements made possible to adapt the rental offer while meeting by the creation of new typologies the needs for the families (SOC.2, SOC.3) and to reduce passively the consumption of energies of more than 50%, mainly by the addition of the winter gardens (TEC.2).
The intervention was completed at half the cost of demolition and new build, an exemplary lesson of transformation of the cities (CON.2).

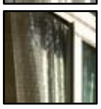
Summary:
STR.0) Structure > Heavy strategy
ARC.0) Architecture > Radical strategy
SOC.0) Society > Heavy strategy
FUN.0) Function > Heavy strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

Material palette:

Steel and glass



Solar curtain

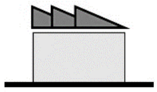


Thermal curtain

Polycarbonate screen

DATA SHEET N. 42


Action: volumetric/spatial



Contrast

A green village in the sky.

General data:

Project: Over elevation
Site: Cinisello Balsamo, Italy
Architect: Studio Albori
Client: ALER Lombardia
Construction: 80s
Renovation: 2004-2007
Typology: tower house
Target: social housing

Data collection:

The pilot project aims at creating a green roof that could be also an urban square for the inhabitants of the social housing building. The approach of densification is interpreted in a sustainable way, in terms of materials and solutions (TEC.1, TEC.2).
The two social housing buildings are redesign for a rooftop expansion: the first step was the demolition of the pitched roof in sheet metal and subsequently two series of terraced houses with balcony access were built on the ninth floor.
The new houses are made with wood and metal and they have green roofs for better thermal performance, especially in summer, and in order to allocate a private garden for each of the apartment underneath (ARC.1, FUN.3, TEC.1, TEC.2).
The small constructions have access routes and they share a communal building with its square-garden (FUN.1, FUN.2, FUN.3), generating a urban micro-environment with a panoramic view of the city and of the distant mountains (ARC.2, ARC.3).
Although the construction process suffered of many management problems (CON.1, CON.3), the inhabitants were able to restore the architectural dignity of the project personalizing the environment and the apartments. The narrow spaces create spontaneously many occasions of meeting and cohesion, with the actual requalification of the social housing buildings promoting again a living style based on sharing (SOC.1, SOC.2, SOC.3).

Summary:
STR.0) Structure > Light strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Radical strategy
FUN.0) Function > Medium strategy
TEC.0) Technique > Medium strategy
CON.0) Construction > Ineffective strategy

Material palette:



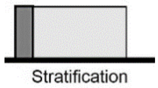
Wood


Metal


Green roof

DATA SHEET N. 43

Action: superficial/two-dimensional



A new highly performing aluminium envelope.

General data:

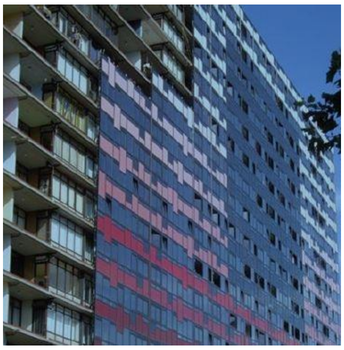
Project: Torenflat
Site: Zeist, Netherlands
Architect: Frowijn de Roos
Client: Vestia
Construction: 1974
Renovation: 2010
Typology: tower
Target: apartments

Data collection:

The building, of nineteen floors, has 484 apartments and its dimensions are 108 m length, 27 m width and 58 m height. Almost 1100 people live in the east and west facing apartments, which provided the architects a big challenge during the renovation process of the two facades (CON.1). Nevertheless, the final approach provided not only high quality architectonic and energy saving solutions but also the least disruption to residents (ARC.1, TEC.2, CON.1).
The new facades are realized with elements in prefabricated and partially recycled aluminium and glass (TEC.1), able to eliminate thermal bridging and to renovate the architectural appearance of the building (ARC.2, TEC.2, TEC.3). The new look is completely different from the former one and the massive character of the building is attenuated with the use of different nuances of the opaque aluminium spandrel panels (ARC.2, ARC.3).
To minimize noise during the building phase, the architects chose a façade system that required the least number of holes to be drilled into the existing concrete structure: just three fixing points are necessary for every unit and the holes for the former balcony balustrade have been used for the new façade assembly (CON.1).
The speed and logistics of the façade refurbishment were impressive with around 200 sqm of new façade installed within a single day (CON.1, CON.3). The homogenous façade has turned former balconies into loggias, increasing the living space in each of the apartments (FUN.1).
The new façade has significantly improved the level of comfort in the building, with better energy performances and lower consumptions (TEC.2); the improvement in living standards had also a positive effect on the decreased rate of change in tenants per year (SOC.2, SOC.3).
The decision to refurbish the building complex has had an impact on the development of the neighbourhood: a new expansion with common services and facilities were built (ARC.2, SOC.2, SOC.3, FUN.2).
The modernized apartment block received two awards for the category residential renovation and for energy efficient buildings, reached with relatively minimal investments (CON.2).

Summary:
STR.0) Structure > Medium strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Heavy strategy
FUN.0) Function > Heavy strategy
TEC.0) Technique > Radical strategy
CON.0) Construction > Radical strategy

Material palette:

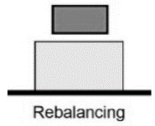


Prefabricated and partially recycled aluminium

Glass

DATA SHEET N. 44

Action: volumetric/spatial



A roof stockpile expansion.

General data:

Project: Hellwagstraße 6-8
Site: Wien, Austria
Architect: DI Heinz Lutter
Client: -
Construction: 1980
Renovation: 2003
Typology: patio house
Target: mixed

Data collection:

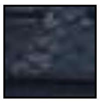
This property is part of a massive apartment building with a flat roof: six stairwells connect 240 medium and small apartments (FUN.3). The apartments have good thought out and efficient floor plans (ARC.3). A series of horizontally positioned loggia-bands between the closed exterior walls provide structure to the façade (STR.1, ARC.3).
The forty-one new apartments are designed as roof stockpile following the principle of the existing building. The new roof structure consists of a rhythmical series of vertical and inclined exterior wall surfaces with recessed terraces in between (FUN.1).
Two front facing wood laminate strips in the parapet area and at the top edge of the roof connect these different elements (TEC.1). The lower strip forms the terrace railing; the upper strip provides sun protection for the terraces (TEC.2). This horizontal layout creates a unified structure as new finish for the massive building block (ARC.3).

Summary:
STR.0) Structure > Light strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Unknown strategy
FUN.0) Function > Light strategy
TEC.0) Technique > Light strategy
CON.0) Construction > Unknown strategy

Material palette:


Laminate wood


Wood shingles


Black tiles

DATA SHEET N. 45

Action: volumetric/spatial

Selection

Recovering the streets in the sky.

General data:

Project: Park Hill
Site: Sheffield, Great Britain
Architect: Hawkins-Brown and Egret West
Client: Urban Splash and public partners
Construction: 1961
Renovation: 2011
Typology: patio house
Target: mixed

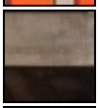
Data collection:

Built on one sloping hill, the construction is an important landmark for the city (ARC.2).
The complex accounted of 998 flats, popular place to live until the 80s when unemployment and crime increases made the complex an undesirable place to live (ARC.2). The building was saved from demolition thanks to the acknowledgement of its architectural and historical significance, being one of the first completed schemes of post-war slum clearance and the most ambitious inner-city development of its time (ARC.1, ARC.2, TEC.1, CON.1).
The redevelopment exploits the potentialities of the original design: the dual aspect arrangement, the natural ventilation and district heating system, the presence of a private balcony for each flat, the orientation of the flats with living spaces facing South and West and bedrooms facing North or East and the external accesses called “streets in the sky” (SOC.3, FUN.3, TEC.2). Additionally, the refurbishment maintains the integrity of the original structure with duplex and single level apartments arranged within a rigid grid with access decks on every third floor serving duplexes on and above the deck and single-story flats set below (STR.1, ARC.3). The existing concrete frame was repaired and a new façade installed including the iconic “streets in the sky” (STR.1, STR.2, STR.3). The colourful anodised aluminium panels of the facades replicate the coloured brick tones of the original façade and emphasise the modular structure (ARC.3, TEC.1). The new balustrades present a more slender design while looking almost identical to the original concrete ones (ARC.3, TEC.1). The North and East elevations present a new solid to void ratio: this gives previously dark bedroom spaces much more daylight (TEC.2).
In the Northwest block, a four-story cut creates a welcoming new entrance to the estate and, on the West façade, an external mirror-finished stainless steel helical stair and glazed external lift core provides vertical circulation and panoramic views, while underlining the entrance (ARC.2, ARC.3, FUN.3, TEC.1).
One of the failures of the original scheme was the allocation of residential units at ground level, which proved problematic for privacy and management. In the refurbished scheme the ground level is devoted entirely to commercial, retail, bar and restaurant uses (FUN.2). It is marked by a different elevation language of clear flush glazing to demarcate it from the residential units, ensuring a sense of transparency at the base of the building (ARC.3). The families were re-homed next to their neighbours to maintain a strong sense of community (SOC.1).

Summary:
STR.0) Structure > Medium strategy
ARC.0) Architecture > Medium strategy
SOC.0) Society > Heavy strategy
FUN.0) Function > Heavy strategy
TEC.0) Technique > Medium strategy
CON.0) Construction > Medium strategy

Material palette:

Anodised aluminium panels

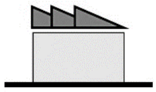


Concrete

Mirror-finished stainless steel

DATA SHEET N. 46

Action: volumetric/spatial



Contrast

A formally separate building built on top of an existing house.

General data:

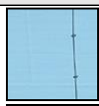
Project: Spitalgasse 25, Wien 9
Site: Wien, Austria
Architect: Lutter Heinz
Client: -
Construction: -
Renovation: 2003
Typology: patio house
Target: apartments

Data collection:

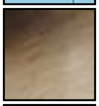
This project has experienced a wide debate within the public, being a strong intervention on a historical building (ARC.1). The new object is an indipendent extension of the existing attic that is converted in two-storey apartments with a gallery level (ARC.2, ARC.3).
All load bearing walls and ceilings are constructed from prefabricated wooden elements added onto the existing building in only 14 days (STR.1, TEC.1, CON.1, CON.3). The wooden façade is treated in a protective coating of light-blue elastomer polyester (ARC.2, ARC.3, TEC.1, TEC.2).
This innovative construction will break through the limits of view that are usually present in loft constructions.
The apartments, which are partially two-storied, will take advantage of the exterior form for gallery floors and the available airspace, and thus available views between the planes. All apartments will be facing the street and the courtyard. The apartments offer great views over the city as well as nearby attractions (ARC.2).
In addition, the apartments will take in the soothing calmness of the inner courtyard.
The open rooms as well as the significant form provide for a new way of living above the rooftops (ARC.2, ARC.3).

Summary:
STR.0) Structure > Medium strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Light strategy
FUN.0) Function > Light strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

Material palette:



Wood with protective coating of light-blue elastomer polyester



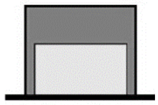
Prefabricated wooden elements

Steel

Glass

DATA SHEET N. 47

Action: volumetric/spatial



Absorption

A safe fortress made of diamonds.

General data:

Project: Veilige Veste
Site: Leeuwarden, Netherlands
Architect: KAW architects
Client: WoonFriesland
Construction: 70s
Renovation: 2012
Typology: patio house
Target: victims of human trafficking

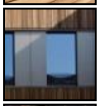
Data collection:

The revolutionary project unifies design, energy reduction (TEC.2) and social security for the victims of human trafficking (SOC.1).
The new building is bold and safe, not hiding itself anonymously but shining in the sun of a new future, providing security and protection for the girls who need to build up again their lives (ARC.3, SOC.1).
The building seems new but it was in the past a police station poorly insulated and needing a redevelopment (TEC.3).
A new envelope covers the entire building with especially designed square composite elements: diagonally angles squares are positioned alternatively on the facades to create a diamond pattern (ARC.3).
The double three-dimensional facades interact with the typical changing light of the Dutch environment and the white cladding mirrors the surrounding landscape with multifaceted effects (ARC.2, ARC.3).
On the ground floor, wooden panels and large windows give the perception of a building floating over the ground level, which enhance the concept of a fortress (TEC.1, ARC.3). In this floor there are offices, meeting rooms and treatment rooms (FUN.2). The girls live instead on the first and second floor, divided into six groups.
An internal big patio is the common open-air space for the girls, who can meet together in tranquillity and protection (SOC.1, SOC.3, FUN.3). The architectural language of the patio is completely different from the outside, because it wants to recreate a more intimate and relaxing atmosphere (ARC.3). Bronze materials and wood create a defined contrast with the white and bold external skin (TEC.1).
The former office block is also the first one in the country to be renovated according to the Passive House Standard and it results in ultra-low energy buildings with limited need of space for heating and cooling (TEC.2).
Indeed the former structure, which being outside created huge thermal bridges, is now enveloped in the new skin and a thick layer of insulation (STR.1, TEC.1, TEC.2).

Summary:
STR.0) Structure > Medium strategy
ARC.0) Architecture > Radical strategy
SOC.0) Society > Radical strategy
FUN.0) Function > Heavy strategy
TEC.0) Technique > Radical strategy
CON.0) Construction > Medium strategy

Material palette:

Wood



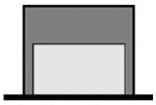
Bronze metal and glass

Timber structure

Composite panels

DATA SHEET N. 48

Action: volumetric/spatial


Absorption

Social diversity and revitalization of the neighbourhood.

General data:

Project: Wijnand Nuijenstraat
Site: Amsterdam, Netherlands
Architect: van den Brink en Tupker
Client: Alliance Amsterdam
Construction: 1959
Renovation: 2007
Typology: gallery house
Target: mixed

Data collection:

The building block has suffered in the past of management problems and thermal and acoustic deficiencies so that it was decided to demolish it and rebuild in the same area (TEC.3, CON.1). Being demolition and reconstruction too expensive, the remaining option was to renovate the building creating a more differentiated provision of dwellings for a wider group of users. Indeed, besides lower social groups also social middle class was meant to occupy the building in order to create social diversity and new cohesion giving a positive impulse to the entire district (SOC.1, FUN.2).The block was a portico building with identical dwellings on each level but with the addition of a new gallery it was possible the diversification of the provision (FUN.2, FUN.3).

The former portico remains though, and it is still the main access to the first three floors, which maintained the same plan scheme and are occupied by families of the low-income groups (SOC.2, FUN.3). The dwellings located on the ground floor have an own front door on the street side, opening the building also to users with disability (FUN.3).

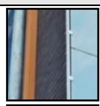
Even if the intervention seems to have changed radically the image of the building, the differences are restricted mainly to the new materials used for the cladding while the floor plans of the first storeys remained untouched (ARC.3, TEC.1). This happened because of the rigid frame grid of the existing building, which partially limited the architectural, structural and technological choices (STR.1, ARC.3, TEC.1). For this reason the only direction of expansion could be on the roof that from pitched became flat (STR.3, ARC.3).

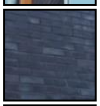
The new maisonettes for the middle class located at the upper floor are accessible from an independent elevator and staircase, added in the redesign; an external gallery is added beside the fourth floor to reach the duplex which are organized way differently from the dwellings in the lower floors (FUN.3).

The addition of the new mass on the upper floors required the use of light technologies so the floors are made of polyester and the walls have timber frames with glass plates combined with zinc cladding and some small brick parts. The new gallery is instead made of plastics (TEC.1, TEC.2, CON.1).

Summary:
STR.0) Structure > Light strategy
ARC.0) Architecture > Heavy strategy
SOC.0) Society > Heavy strategy
FUN.0) Function > Heavy strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

Material palette:

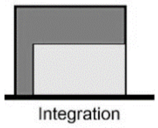

Timber frame and glass plated


Bricks


Zinc cladding

DATA SHEET N. 49

Action: volumetric/spatial



A complex stratification of volumes and languages.

General data:

Project: Dillenburgh
Site: Leidschendam, The Netherlands
Architect: Heren 5
Client: Vidomes, Leidschendam city
Construction: 50s-60s
Renovation: 2010
Typology: mixed
Target: mixed

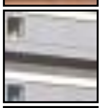
Data collection:

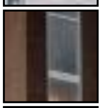
The area was once a popular place to live, with all the services and facilities of a small village but now affected by obsolescence and needing deep interventions (SOC.3, TEC.3). For this reason an urban plan was developed, with the construction of green areas and new common facilities (ARC.2, SOC.3, FUN.2).
The building was emptied, keeping the structure still efficient, and filled again with new plans and contemporary comforts (STR.1, STR.2 ARC.3, FUN.3, TEC.2). The project provided different typologies of apartments: for young families and luxury houses for elderly people plus common areas for social cohesion (SOC.2, FUN.2).
Two new volumes are added to the existing building: a horizontal volume with timber cladding and a vertical massive tower with stone finishing. Every component has its own character given by the use of different natural materials: stones for the tower, bricks for the existing part and wood for the horizontal expansion (STR.1, ARC.3, TEC.1).
The horizontal component has a key role for the connection at the ground level, providing new space for social and common activities (FUN.1, FUN.2, FUN.3).
The horizontal lines of the former building continue in the new expansion merging every part of the project in this way the different volumes are completely merged together in a unified building (ARC.3).
All the parapets are in glass, partially transparent and, in correspondence with the bedrooms, partially opaque in order to maintain a greater privacy for the users (TEC.1, TEC.2).
An important factor for the revitalization of the area was the involvement of the inhabitants who participated in the definition of the new characters of their apartments: the residents' affection to the place and their good ideas to enhance the area were the key points for a virtuous and effective recovery project (SOC.1, SOC.2, SOC.3).
The architects give great importance also to sustainability, with a thermic plan for accumulation of energy on the roof, floor heating system and mechanical ventilation with the improvement of the insulation (TEC.2).
The approach could seem controversial but the awareness of the historical and cultural importance of the building is higher. The complex dynamics behind revitalization and renovation process at the end can lose the relevance of the existing building to preserve if you look at the final result (ARC.1, ARC.2)..

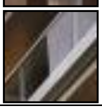
Summary:
STR.0) Structure > Heavy strategy
ARC.0) Architecture > Radical strategy
SOC.0) Society > Heavy strategy
FUN.0) Function > Heavy strategy
TEC.0) Technique > Heavy strategy
CON.0) Construction > Heavy strategy

Material palette:


Timber cladding


Stone cladding


Bricks


Transparent and opaque glass

4.4 Analysis of the results

This paragraph wants to underline some of the key results of the analysis of the best practices in Europe introducing synoptic tables.
The first clear result concerns the recurrence of particular type of approach in particular: superficial or three-dimensional stratifications, and contrast and rebalancing intervention mostly relative to volumetric addition on the roof.
The strategy applied by these projects provides new space and expansions while in the same time improving the energy performance of the buildings. The additions and modifications are realized with dry and lightweight construction technologies so in most of the cases, the inhabitants can stay in their dwellings for the entire construction process and the existing structure is able to bear the new loads without major modifications.
In this way a relative limited amount of economical and material resources are able to solve a complex set of problem, spanning from architectural to technical and technological.

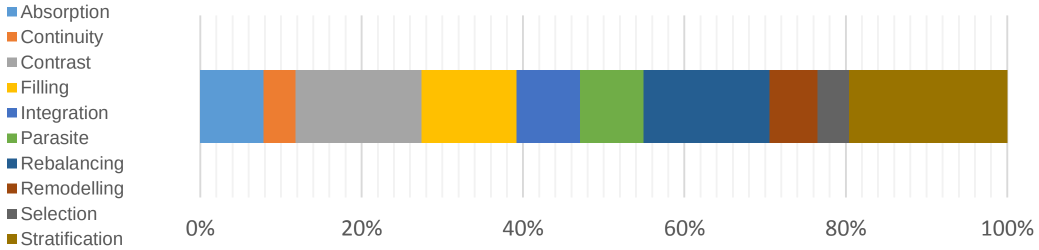
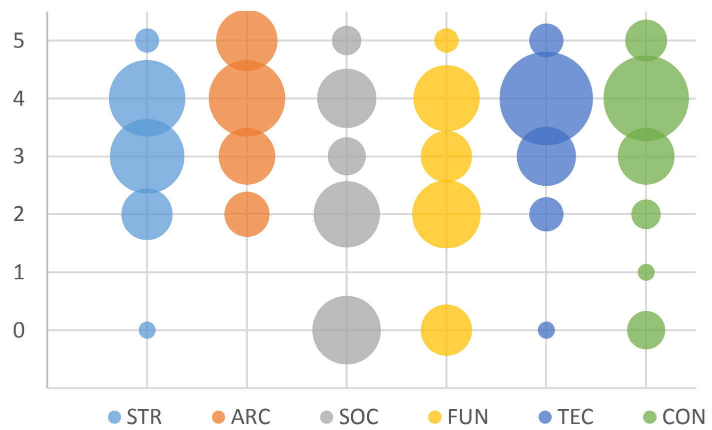


Table 4.4
Percentage of recurrence of the strategies.

Another relevant result is the index of success obtained in the different fields of action individuated. The maximum value that each field can reach is 245 points (5 points for radical strategies multiplied for forty-nine projects) and there are high values in relation to architecture and technique.
On the other hand, the society field reaches only 108 points with a great margin of uncertainty in the design programme. This underlines how the approach to building regeneration, also in these key examples, is still far from the best results that we would aspect.



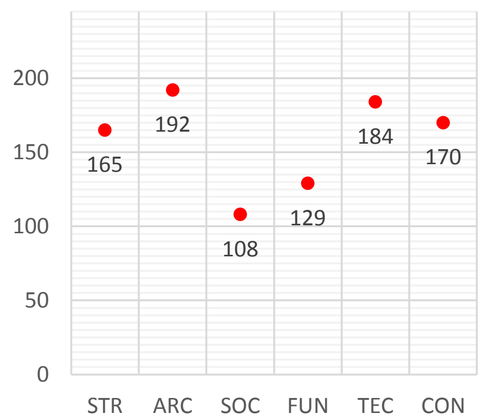
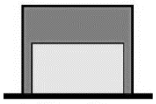
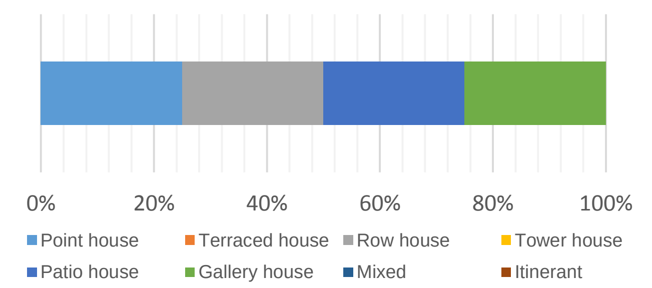
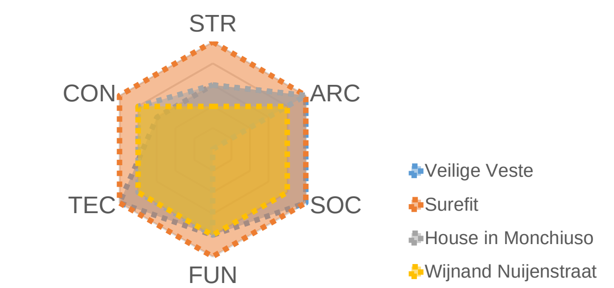
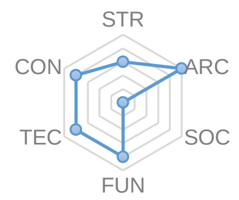


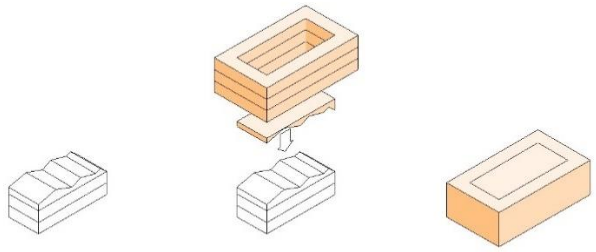
Table 4.5
Index of success for the different fields of action.

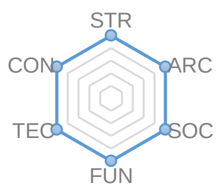

Absorption

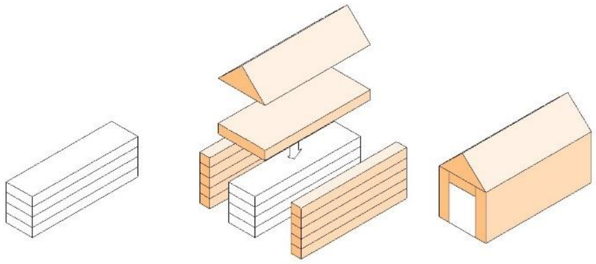

0%
20%
40%
60%
80%
100%
Point house
Terraced house
Row house
Tower house
Patio house
Gallery house
Mixed
Itinerant

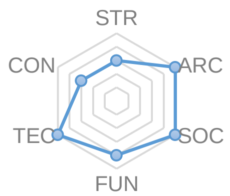

STR
ARC
SOC
FUN
TEC
CON
Veilige Veste
Surefit
House in Monchiuso
Wijnand Nuijenstraat

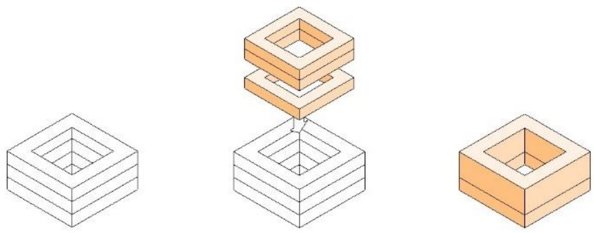

STR
ARC
SOC
FUN
TEC
CON

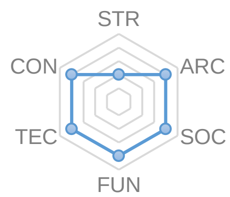


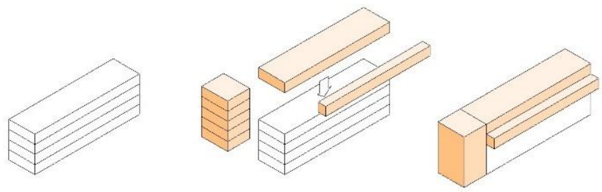

STR
ARC
SOC
FUN
TEC
CON

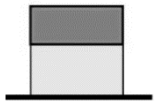


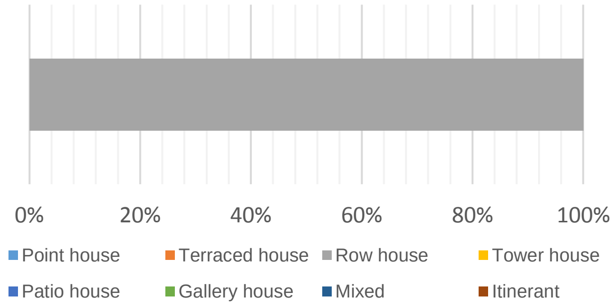

STR
ARC
SOC
FUN
TEC
CON

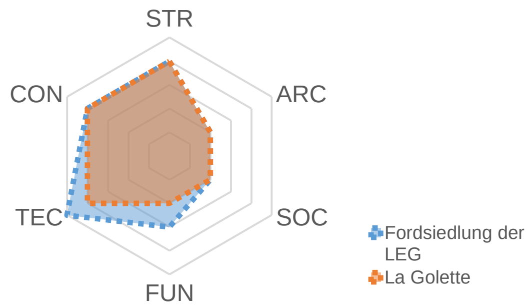


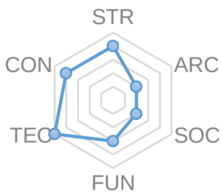

STR
ARC
SOC
FUN
TEC
CON

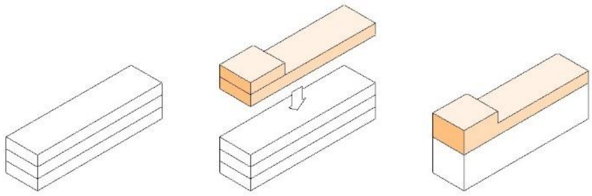


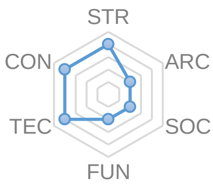

Continuity

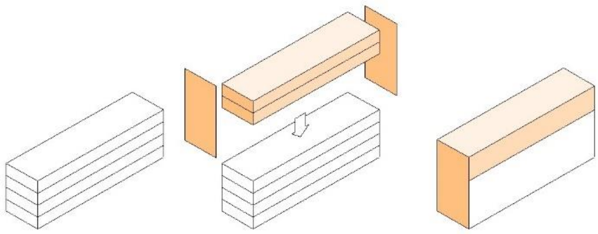

0%
20%
40%
60%
80%
100%
Point house
Terraced house
Row house
Tower house
Patio house
Gallery house
Mixed
Itinerant


STR
ARC
SOC
FUN
TEC
CON
Fordsiedlung der LEG
La Golette

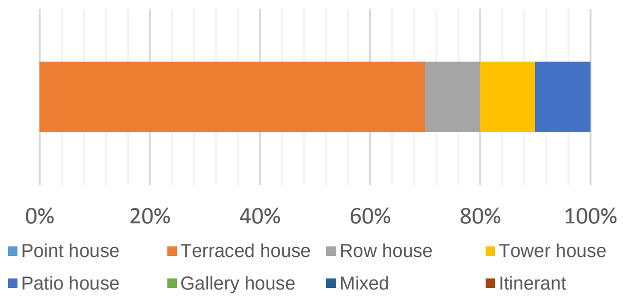

STR
ARC
SOC
FUN
TEC
CON

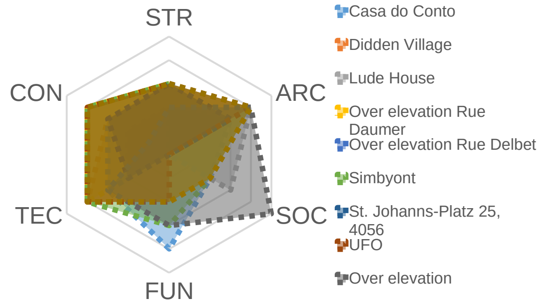


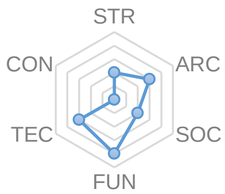

STR
ARC
SOC
FUN
TEC
CON

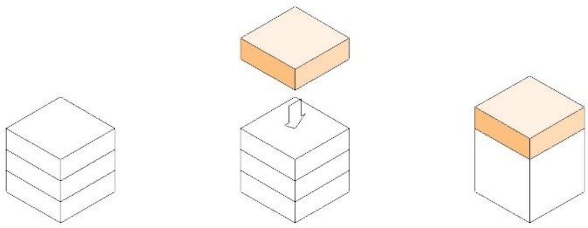


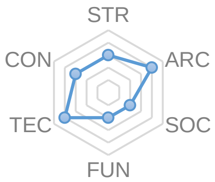
Contrast

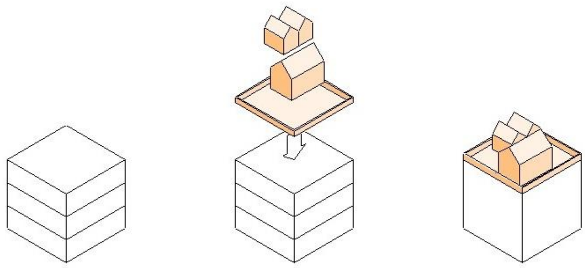

0%
20%
40%
60%
80%
100%
Point house
Terraced house
Row house
Tower house
Patio house
Gallery house
Mixed
Itinerant

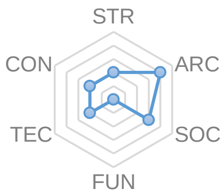

STR
ARC
SOC
FUN
TEC
CON
Casa do Conto
Didden Village
Lude House
Over elevation Rue Daumer
Over elevation Rue Delbet
Simbyont
St. Johanns-Platz 25, 4056
UFO
Over elevation

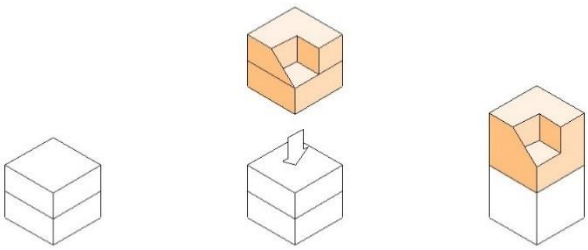

STR
ARC
SOC
FUN
TEC
CON

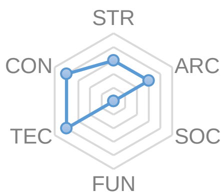


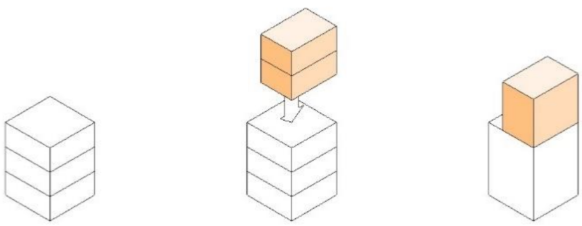

STR
ARC
SOC
FUN
TEC
CON

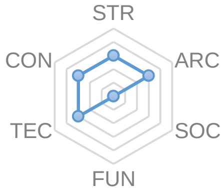
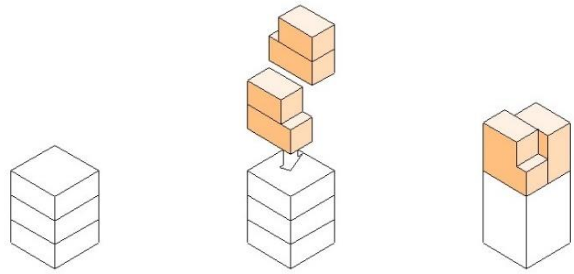
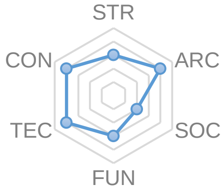
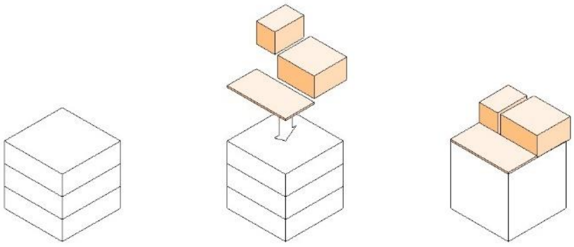
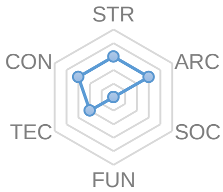
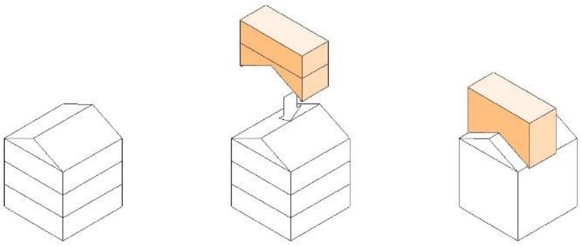
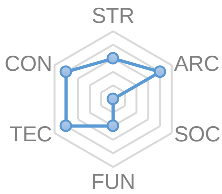
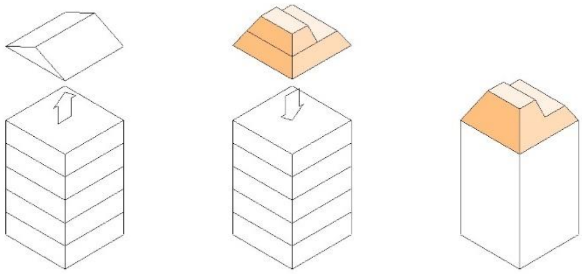
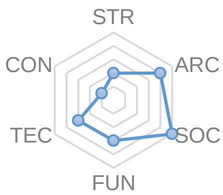
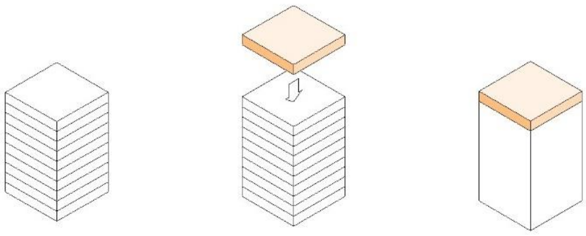


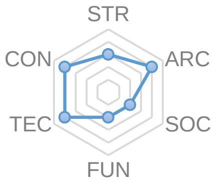
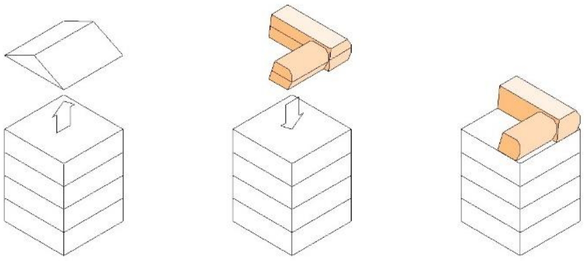

STR
ARC
SOC
FUN
TEC
CON

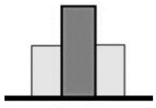


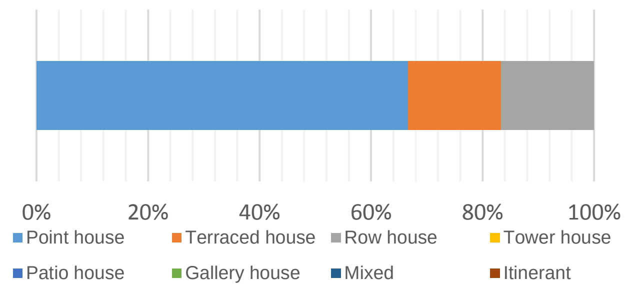

STR
ARC
SOC
FUN
TEC
CON

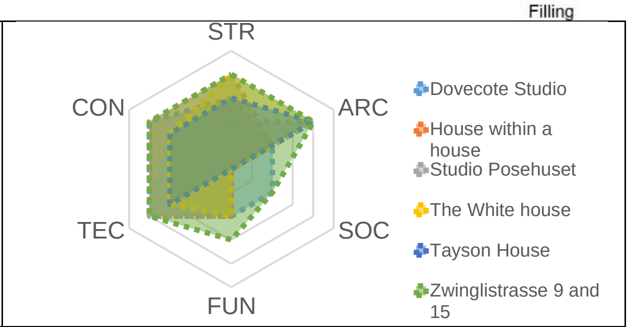


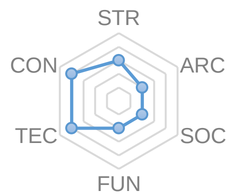
	 STR ARC SOC FUN TEC CON	
	 STR ARC SOC FUN TEC CON	
	 STR ARC SOC FUN TEC CON	
	 STR ARC SOC FUN TEC CON	
	 STR ARC SOC FUN TEC CON	

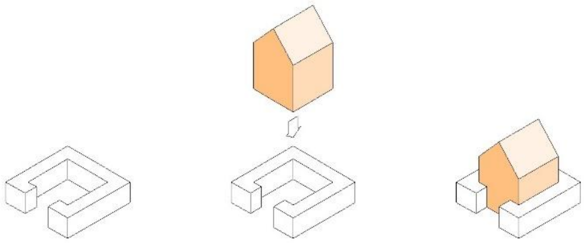
	 	

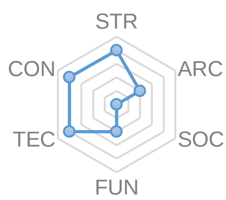

Filling

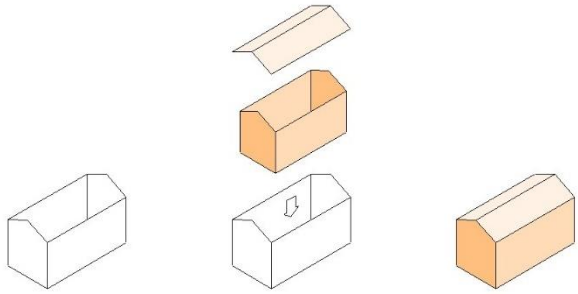

0%
20%
40%
60%
80%
100%
Point house
Terraced house
Row house
Tower house
Patio house
Gallery house
Mixed
Itinerant

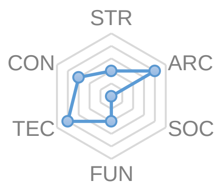

STR
ARC
SOC
FUN
TEC
CON
Dovecote Studio
House within a house
Studio Posehuset
The White house
Tayson House
Zwinglistrasse 9 and 15

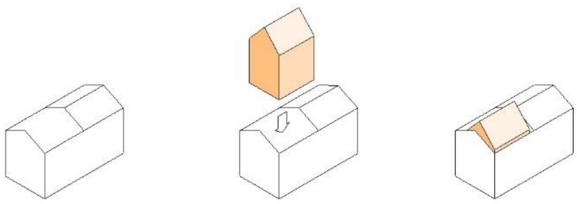

STR
ARC
SOC
FUN
TEC
CON

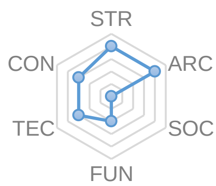


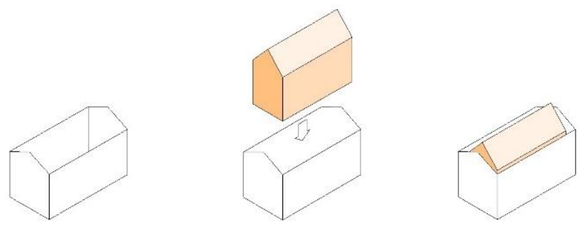

STR
ARC
SOC
FUN
TEC
CON

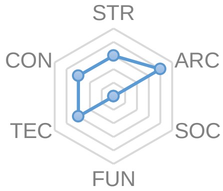
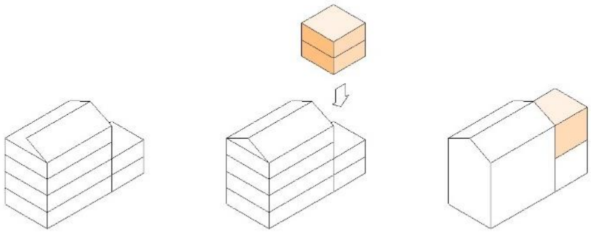
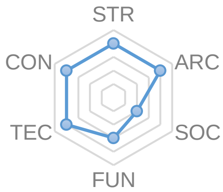
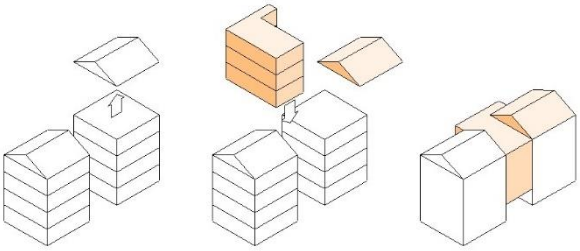


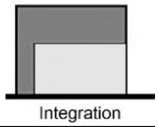

STR
ARC
SOC
FUN
TEC
CON

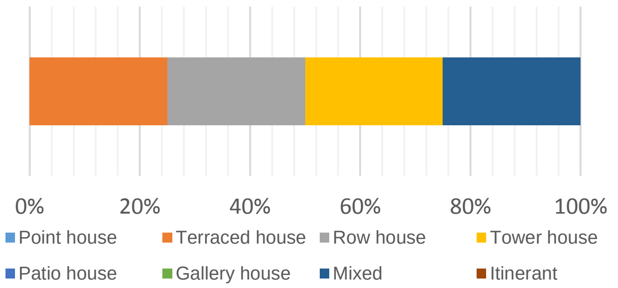


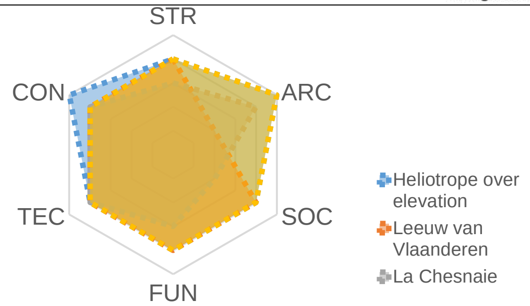

STR
ARC
SOC
FUN
TEC
CON

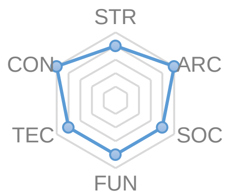


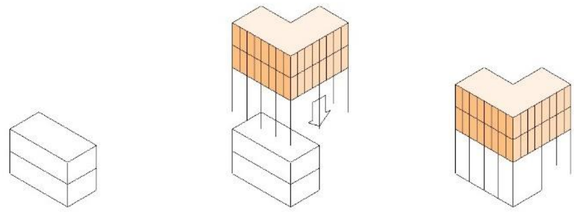
	 STR ARC SOC FUN TEC CON	
	 STR ARC SOC FUN TEC CON	

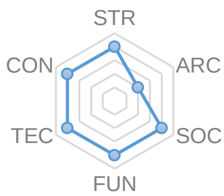

Integration

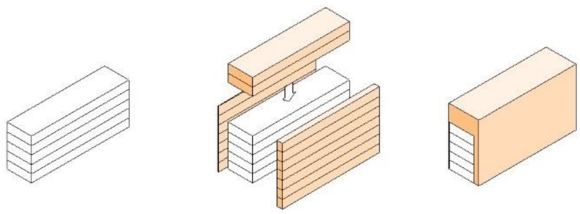

0%
20%
40%
60%
80%
100%
Point house
Terraced house
Row house
Tower house
Patio house
Gallery house
Mixed
Itinerant

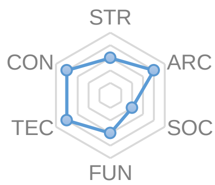

STR
ARC
SOC
FUN
TEC
CON
Heliotrope over elevation
Leeuw van Vlaanderen
La Chesnaie

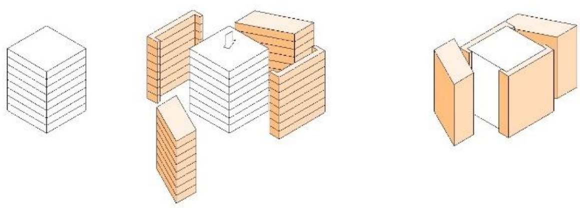

STR
CON
ARC
TEC
SOC
FUN

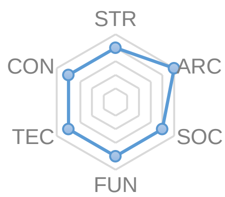


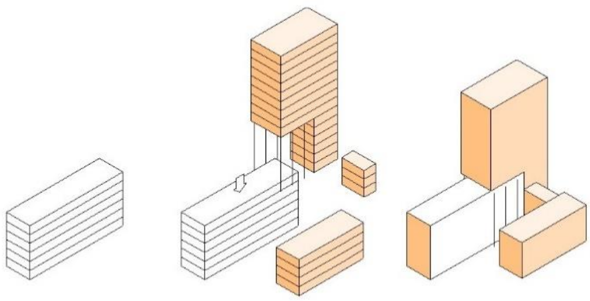

STR
CON
ARC
TEC
SOC
FUN

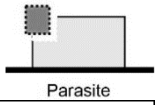


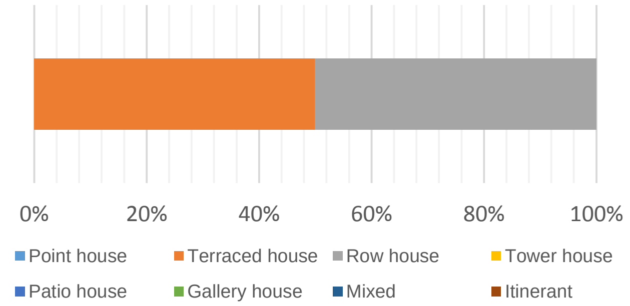

STR
CON
ARC
TEC
SOC
FUN

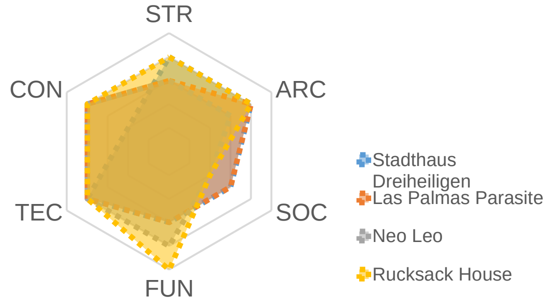


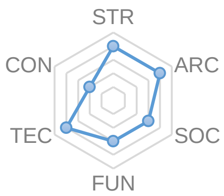

STR
CON
ARC
TEC
SOC
FUN

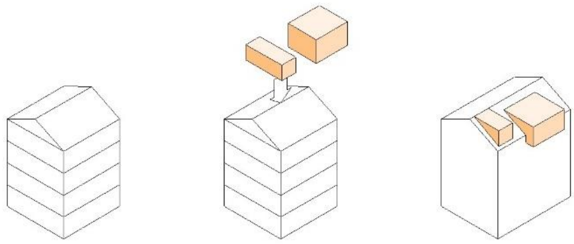


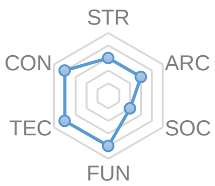

Parasite

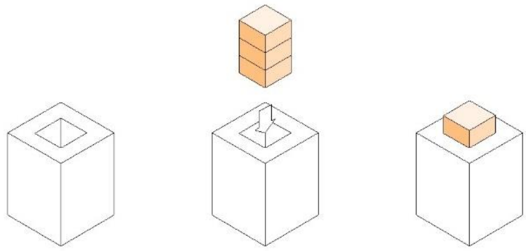

0%
20%
40%
60%
80%
100%
Point house
Terraced house
Row house
Tower house
Patio house
Gallery house
Mixed
Itinerant

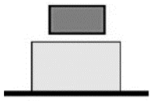

STR
CON
ARC
TEC
SOC
FUN
Stadthaus Dreiheiligen
Las Palmas Parasite
Neo Leo
Rucksack House


STR
CON
ARC
TEC
SOC
FUN

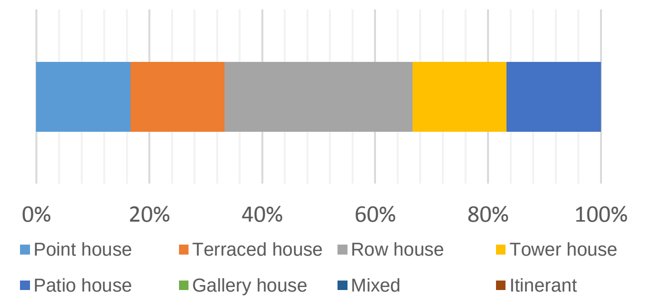


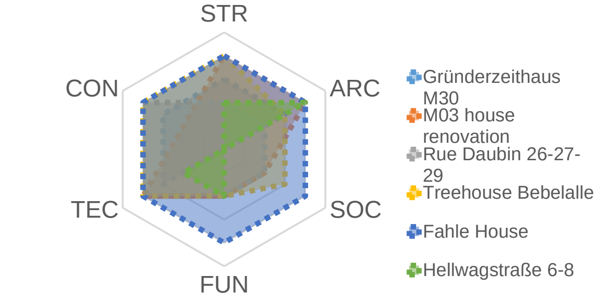

STR
CON
ARC
TEC
SOC
FUN

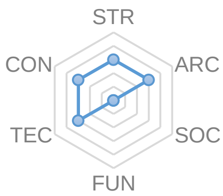


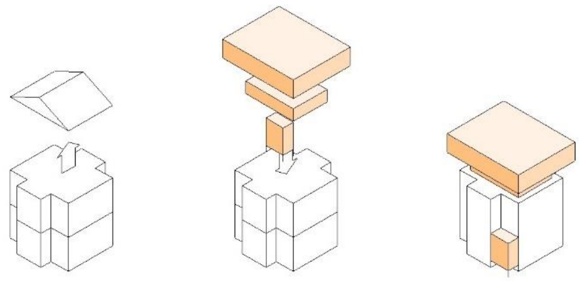


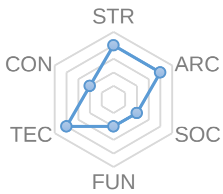
Rebalancing

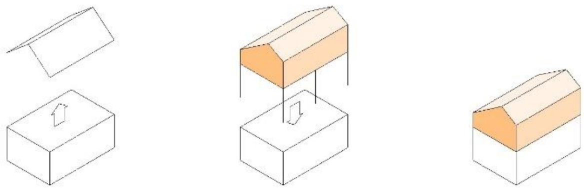


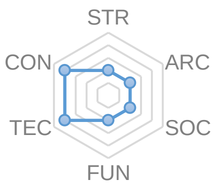


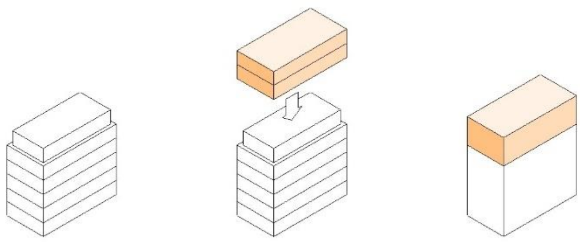


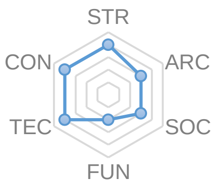


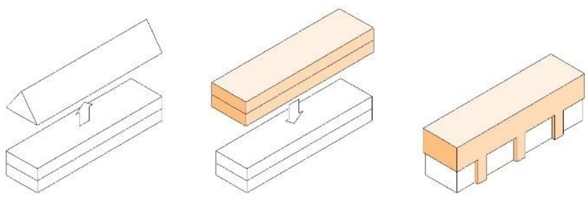


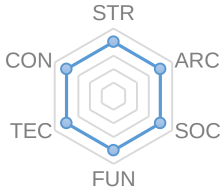
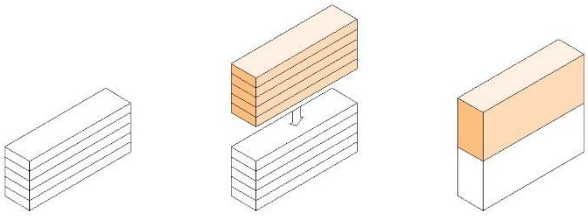
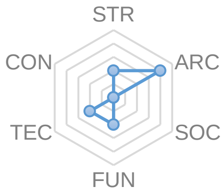
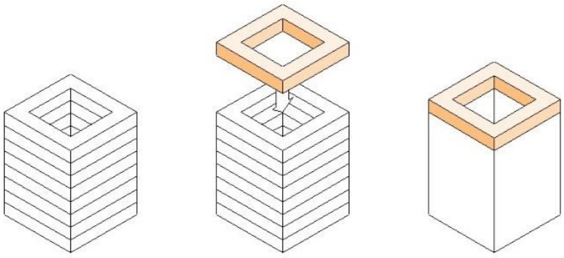


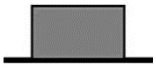




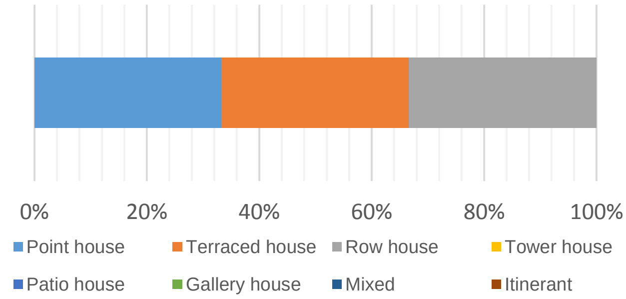


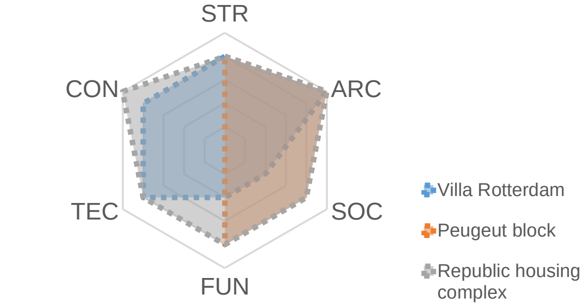


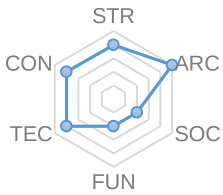
	STR ARC SOC FUN TEC CON	
	STR ARC SOC FUN TEC CON	

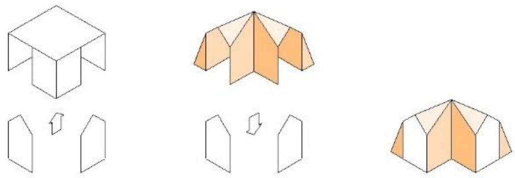


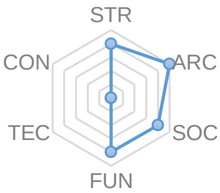
Remodelling

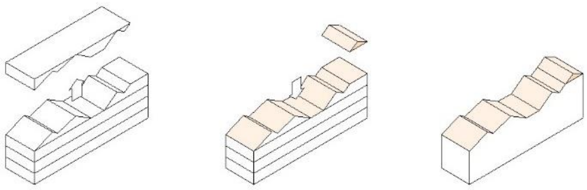


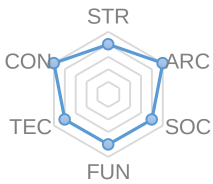


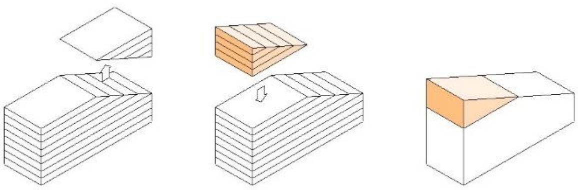


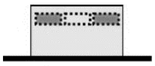




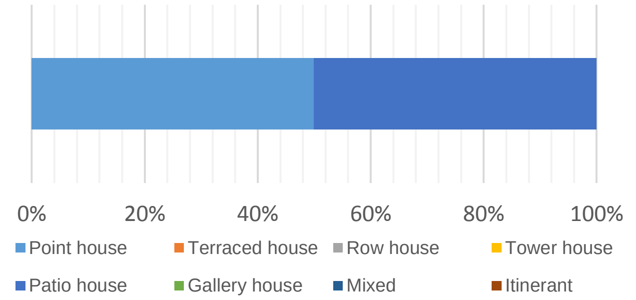


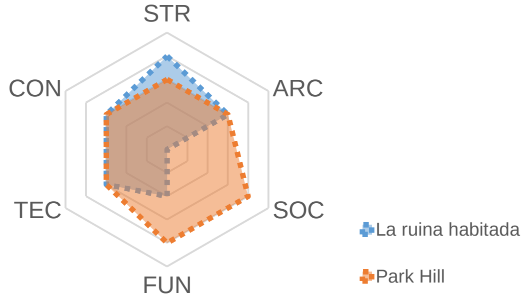


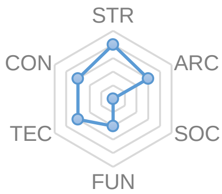


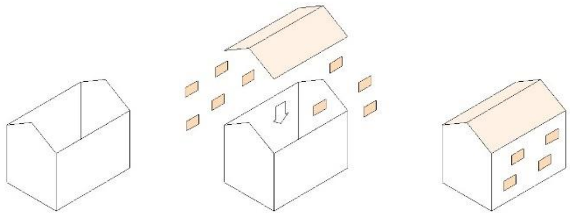


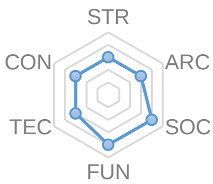
Selection

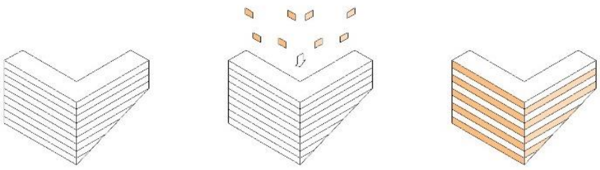

0%
20%
40%
60%
80%
100%
Point house
Terraced house
Row house
Tower house
Patio house
Gallery house
Mixed
Itinerant

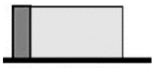

STR
ARC
SOC
FUN
TEC
CON
La ruina habitada
Park Hill


STR
ARC
SOC
FUN
TEC
CON

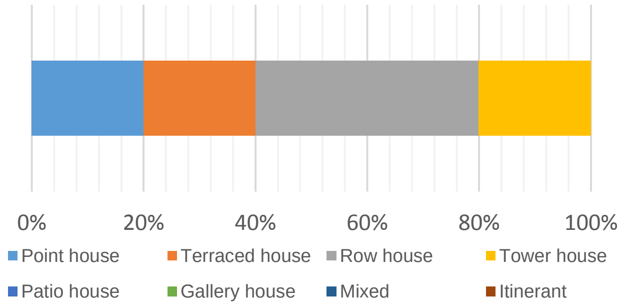


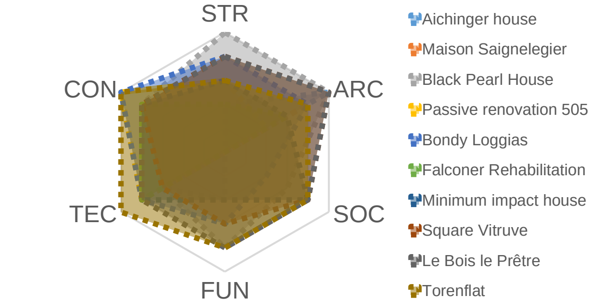

STR
ARC
SOC
FUN
TEC
CON

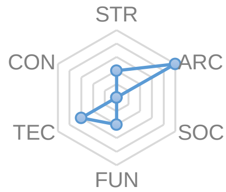


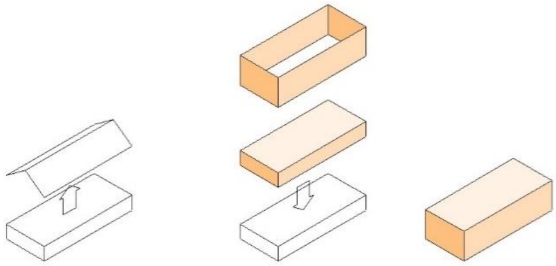


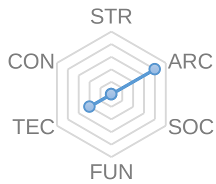
Stratification

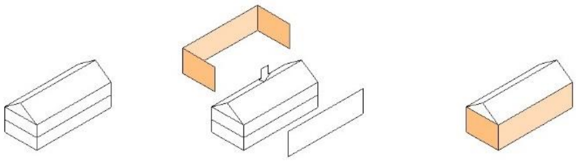


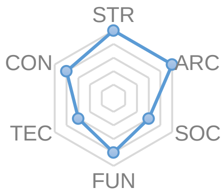


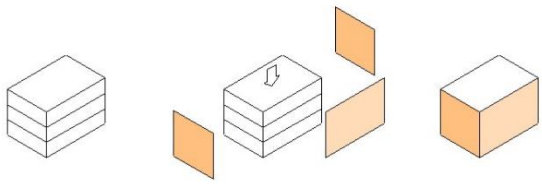


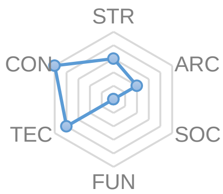


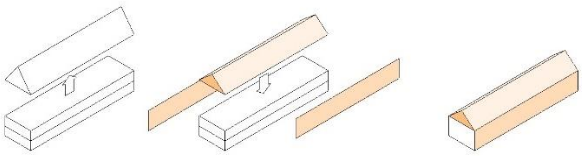


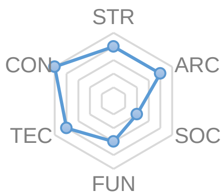


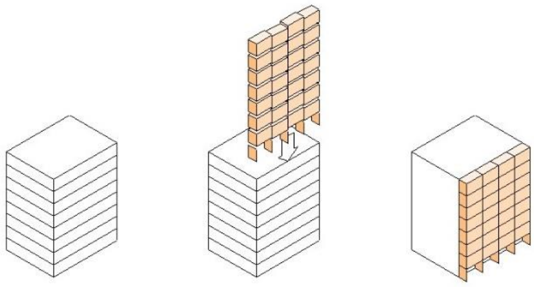


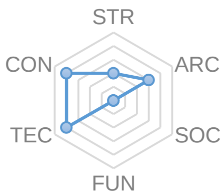


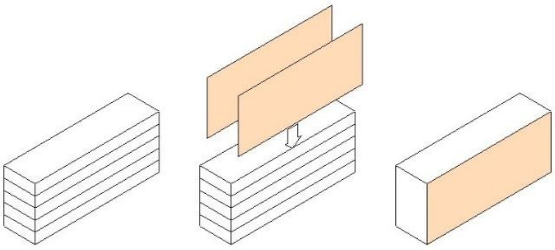


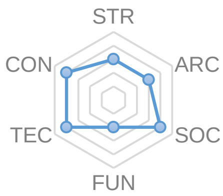


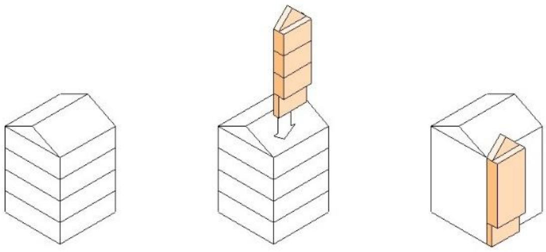

STR
ARC
SOC
FUN
TEC
CON

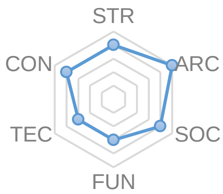


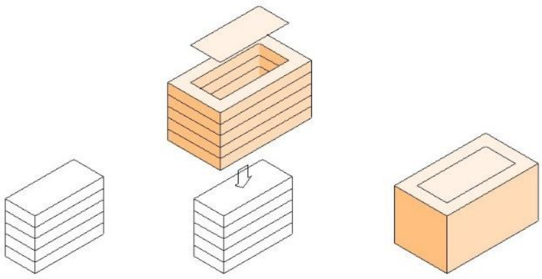

STR
ARC
SOC
FUN
TEC
CON

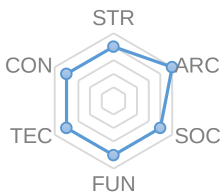


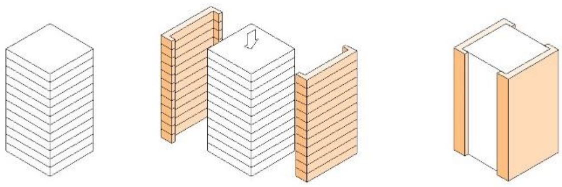

STR
ARC
SOC
FUN
TEC
CON

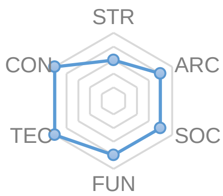


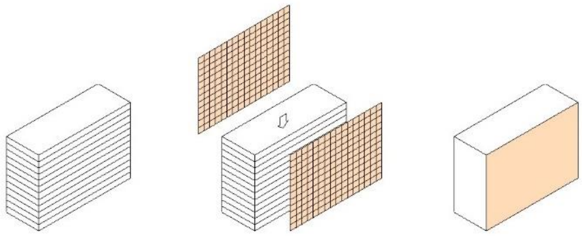

STR
ARC
SOC
FUN
TEC
CON




STR
ARC
SOC
FUN
TEC
CON



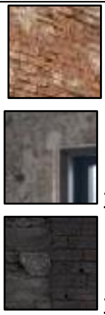

STR
ARC
SOC
FUN
TEC
CON



STRUCTURE

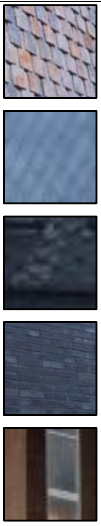




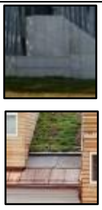
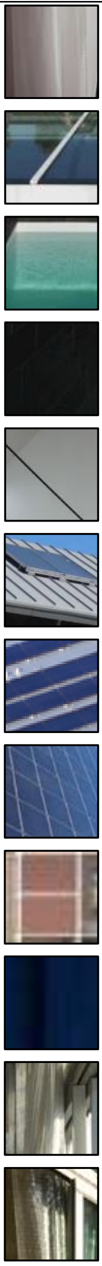



METAL	CONCRETE	WOOD		BRICKS	STONE
2	12	3	37	6	9
6	13	5	41	11	12
16	21	6	43	16	16
17	24	10	45		38
23	38	10	45		
26	44	11	46		
27		14	47		
28		14	49		
32		18	50		
34		19			
36		22			
39		23			
40		24			
51		26			
		29			
		33			
		36			

CLADDING AND FINISHING

METAL	TILES	PAINTING	WOOD		GLASS	OTHER
						
7	19	3	2	43	38	1
8	20	4	3	46	47	7
16	43	7	4	48		11
17	47	8	7	49		11
18	48	9	8	51		15
21		10	9	51		15
23		13	13			22
36		14	14			46
41		20	14			32
42		21	17			32
44		26	21			33
46		30	24			
47		31	29			
		35	31			
		36	31			
		49	35			
		50	35			

DETAILS

METAL	CERAMIC	WOOD	GLASS		GREEN	OTHER
						
5	1	19	2	31	13	1
9	33	20	4	33	10	4
14		23	5	36	17	4
25		25	6	37	17	4
34		27	9	39	21	8
39		49	10	40	33	19
44		51	14	42	41	26
45			17	45	35	27
			18	46	48	34
			19	48		39
			22	49		40
			23			40
			24			
			25			
			28			
			29			
			30			

4.5 Discussion

The context of intervention requires specific technological resources, finalized to the realization of additions, not intended only to cover missing parts, but able to give an answer to the evolution of the needs of users.
It is a design philosophy alternative to demolition and reconstruction, not defining the destiny of the built environment but allowing, stimulating, organising, encouraging, the evolution of the building technologies towards long-lasting solutions.
The study of the state of the art highlighted the leading role of the envelope in defining new characteristics, performances and appearance for the construction.
The envelope can be interpreted as a liminal space between inside and outside, thus regulating the relationship between the building and the environment but also between the building and the users.
The envelope is able to determinate climate control, energy performances, aesthetical values, architectural characteristics, but it is also able to determinate and/or to influence structural stability of the building in relation to the technologies applied (Lovel, 2013).
The final considerations are that an approach directed to the envelope might be an effective strategy of integrated intervention, which can also support the life cycle extension of estates.
The intervention does not mean only a substitution of the existing façade with the aim of meeting higher levels of energy saving and building identity but can also become a way to reduce the seismic vulnerability of the buildings.
In this study, the building envelope is not only defined only as a surface wrapping the building but also as a component which three-dimensional transformation increases or decreases the entire volume. With this respect, additions and subtractions, like attaching building volumes and selective demolition, are incorporated within the range of physical measures for renovation directed to the envelope.
The scale of envelope directed approach is technically limited to the single estate, but since a number of measures involve the immediate surroundings, results could reverberate on the urban level as well.
In principle, aspects that could be improved by implementing such a strategy could be distinguished into aspects related to the building and the close surroundings.
Scale of the building:

- energy and technical performances of the façade (therefore of the entire block);
- maintenance (good materials require less expenses and last longer);
- interior comfort and health (high-performance façade improves interior liveability);
- market position of dwellings (thanks to higher quality of dwellings);
- aesthetics (dwellings in attractive blocks can be rented or sold easier);
- differentiation of housing supply (interior walls can be moved to diversify types of dwelling);
- functional flexibility (interior walls can be moved to convert the use from residential to other functions like commercial).

Scale of the neighbourhood:

- accessibility to the building (redefinition of public and semi-public space nearby the block, more safety);
- attractiveness of the neighbourhood (good renovation might attract people living there and improve the image of the area);
- orientation within the area (recognizable façade can help identifying the place where one lives);
- control of public spaces;
- use of the bottom (conversion into functions like shops, culture, education can be used by people living in the area);
- reputation of the area.

5. DESIGN TOOLKIT: ARCHITECTURE, SOCIETY, AND FUNCTION

5.1 Introduction

After the First World War, Europe became the main stage for the experimentation of the new architectural theories of the period.

The Modern Movement sought to find a simplified, abstract mode of expression, to develop a pure conceptual design free from unnecessary ornaments (Acharya, 2013). One of the most important motivations for that was the pioneering view on social matter, for which improving living and working conditions of the nation was the most important agenda of the day.

After the Second World War, one of the most influential representative of the new practice were the Metabolists, a group of excellent Japanese architects that had envisioned a new direction for architecture and urbanism of the XX century. The Metabolists were established in 1960 by the critic Noboru Kawazoe together with the five architects, Kiyoshi Awazu, Kiyonori Kikutake, Kisho Kurokawa, Fumihiko Maki, and Masato Otaka. This first Japanese movement after the Second World War aimed at achieving the synthesis between tradition, technology, human, and nature, manifesting the idea that buildings and cities should develop organically, and grow accordingly to the needs of their inhabitants. In their opinion, the traditionally fixed forms and functions were out-dated (Acharya, 2013).

Their vision resulted in the creation of various architectural projects and urban plans with large, flexible and expandable structures. "The philosophy of metabolic design is based on exchangeability, modular buildings, prefabricated parts and capsules. The units move, change or expand according to the needs of the individual, thereby creating organic growth" (Echavarria, 2004).

The architecture of metabolism, challenging the "machine age", proclaimed an "age of life" (Kurokawa, 1994). In this panorama, it starts to assume relevance the plug-in idea, derived from Le Corbusier design concept of 1947-1952 for the Unite d'Habitation in Marseilles, where a faceless creator inserts prefabricated dwelling units into a structural frame (Frampton, 1980).

In the 1960s, the Archigram's Peter Cook develops the idea to create a Plug-in City composed of prefabricated components - housing, office, and shop modules – inserted on a mega structure with rail-mounted cranes. A squared grid with a life span of forty years, where units are inserted and substituted when needed, constitutes the mega structural frame. The units are projected for obsolescence so to be progressively updated to the best technology of the moment and to the best living standards. In this way, a self-refreshing city would support the growth and the changes of the community.

In the same years, Freidman (1960) developed a theory about providing flexibility through suspended superstructures over the city, allowing inhabitants to construct their own dwellings within the structures: "The essential for the spatial town is what I call 'spatial infrastructure': a multi-level space-frame grid supported by pillars separated by large spans.[…]. This infrastructure represents the *fixed* part of the city; the *mobile* part consists of the walls, floor slabs, partitions, which make possible individually decided space arrangements: the "filling in" within the infrastructure. Thus all elements which are in *direct contact with the user* (i.e. those which he sees, touches, etc.) are mobile, as opposed to the infrastructure which *serves for collective use* and is *fixed"* (Friedman, 1960).

In the 1964, Archigram's Warren Chalk designed a tower of plug-in capsular dwellings, prefabricated modules to be attached in a central core, providing the structural support, accessibility and services. The idea will be later proposed by many different architects, such as Kisho Kurokawa's Nakagin Capsule Tower in Tokyo completed in 1972 or the prototype Industrialized Housing System designed in 1991-1992 by Richard Rogers and Ove Arup.

All these projects essentially rotated a sprawling community into a vertical orientation, promoting a more compact city and higher urban density. These visionary ideas eventually resulted in some extreme projects, such as the Nomadic skyscraper by D'Amico and Tesio, constituted by a fix grid frame where recyclable units can be inserted in order to respond to the temporary housing needs of the modern nomads.

The main concept is that "modern life can no longer be defined in the long term and consequently cannot be contained within a static order of symbolic buildings and spaces" (Rogers, 1997).

At the same time, the bulk of housing demand in developed countries is providing affordable housing. Usually, as money reduces, space shrinks and the role of design becomes more critical, requiring the quality of the design process and of the technical solution.

This chapter will introduce the themes connected with housing adaptability and flexibility, describing the evolution of the concepts and the experimental results. The theme will be also analysed in relation to self-construction and progressive construction, seen as the answers of the architectural flexibility applied at societal level.

5.2 Designing flexibility: architecture, society and function

If social housing is conceived as a static objected, destined to become inadequate and obsolescent, its occupants and their needs change continuously over the time. Human beings are incredibly flexible and adaptable and they desire buildings able to adaptable as well, following their own individuality.

This brings to the abandon of the idea of mass housing as the only response to different historical and cultural contexts, experimenting a new vision of private domain, changing every day and in a long-term vision.

When the need for adaptation is connected with retrofit, the themes on stake are even more complex. Energy and resource saving necessities suggest to maintain as much as possible of the existing conditions, while the modern requirements of a fast and changing community need innovative schemes and solutions.

Recent experiences have shown how the integration of evolutionary and dynamic mechanisms during interventions on the residential heritage can be convenient in a long-term vision, because it grants a longer life span to the building, reducing the need and the frequency for management and maintenance. An intervention conceived in this way adds a greater value to the property, with extra costs relatively low if compared with a traditional approach (Till & Schneider, 2005).

On the other hand, the construction of "static" buildings, corresponding to a specific user target in a certain period, has been considered for a long time convenient for keeping the market in constant demand (Till & Schneider, 2005) because when the dwelling becomes obsolescent for a certain user, the only option is transferring in another place.

Despite these positions, contemporary architecture is starting to recognize the dimension of change in residential design, with visionary projects of buildings and neighbourhood growing and developing in relation to the needs of families and communities.

Today, housing construction is investing in designing new changeable spaces, where flexibility and temporariness are the key features of a successful project.

The "adaptive" residence limits the costs connected to renovation, allowing the typological reconfiguration of the dwellings, incorporating new technologies and upgrading the old ones.

The principle of adaptation can be seen as part of the natural evolution process of a building. Kronenburg (2007) defines adaptability in architecture as the awareness that "the future is not finite, that change is inevitable, but that a framework is an important element in allowing that change to happen".
The "framework" defined by Kronenburg (2007), is the same recognized by the "open building" strategy, which provides a loose-fit space that can be easily reconfigured at the later stage (Kendall & Teicher, 2010). The user covers a predominant role of control, not only after the occupation but also during the design phase. The occupants have the freedom to alter progressively the spaces, instead of having design rules predetermining their lives, and they co-evolve with their own dwellings.
While the principle of adaptability is connected with the capability of different social uses, flexibility is referred to the capability of different physical arrangements, during both the design process and the life cycle (Groák, 2002).
Together these two principles determine the degree of flexibility of an architecture, with a deliberately broad definition that includes the modification of the layouts over time, the potential to incorporate new technologies, the possibility to change demographics or, in extreme case, the same use of the building.
This idea of enabling social and physical change in housing can appear evident, however, despite numerous attempts, it is still not widely accepted.
Nevertheless, the arguments for flexible housing are compelling, because it empowers the user to take control of the design process, it allows the providers to adjust the housing provision to the different living patterns, and it avoids expensive reconfiguration programmes, since the new technology can be easily incorporated.
Adaptability and flexibility are also essential components for achieving sustainable retrofit projects (Acharya, 2013).
The first step to undertake is to operate a strict division between the parts of the buildings that have a longer life span, the structure, and the parts connected with the single dwellings, can be deal with alone.
These single parts can be seen as "fillers" inserted inside the frame structure, which can be substituted for user's need or to be upgraded to better performance standards.
This technique emphasise the use of modern techniques and of prefabricated components but also a strict separation between base components and fillers, to facilitate disassembling and substitution.
A similar concept has been developed recently by different researchers (Di Giulio et al., 2007), such as Ipostudio architects with the project IFD (Industrialised, Flexible and Durable Buildings), a technical solution for the high-tech necessities of flexibility and disassembling.
The project gives to the client the possibility to choose components, materials and finishing from a catalogue of options, reducing the costs of maintenance and refurbishment thanks to the easy substitutions of the components.
The modular approach is developed with a "product platform" including plans for the future, when newer technologies will be available.
The modular architectural parts assure the variety of the dwellings, bringing the responsibility of choice from the producer to the user.
This approach allows strategies in which the producer defines architectures accepting a margin of variation of components, functions, characteristics, and performances.
Modularity in this sense is efficient and completely different from the uniformity of the mass housing, which alone was not able to grant industrialized methods.
In addition, the social trend towards customization of the production, transforms the demand for function more and more individualized and a bigger demand for complexity and variety is promoting the introduction of architectural components with shorter life cycle (Till & Schneider, 2005).
This thesis wants to define a unique model of intervention to solve the complexity of the social housing heritage, characterized by many typologies and technologies, with fast construction process and relatively low costs.

In this optic, prefabricated and optimized components are convenient for large-scale interventions, not giving limitation in terms of architectural characteristics and performances.
The final objective is to use flexible technical systems to achieve a flexible social dimension, with the final objective of self-construction, following the recent trend for the technical solution to become more and more an instrument of the community.

5.3 Evolution of flexible housing solutions from the Second World War up to date

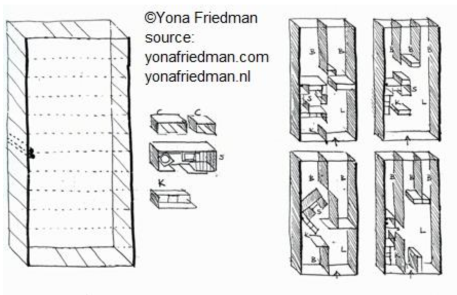
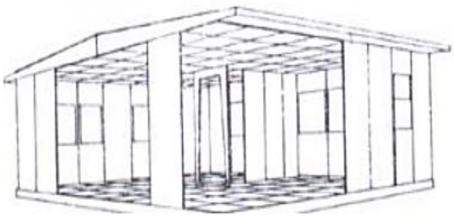
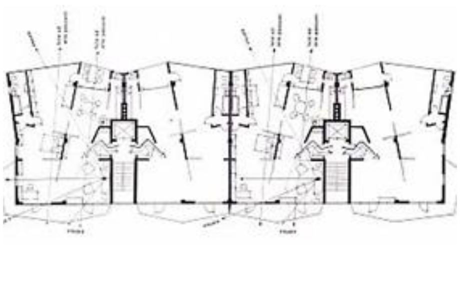
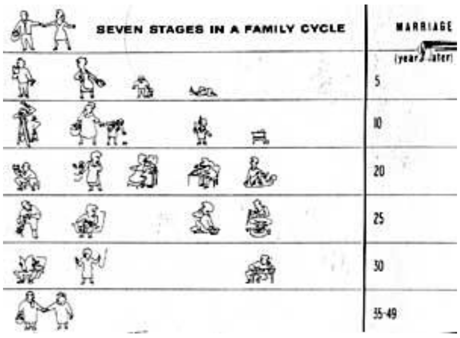
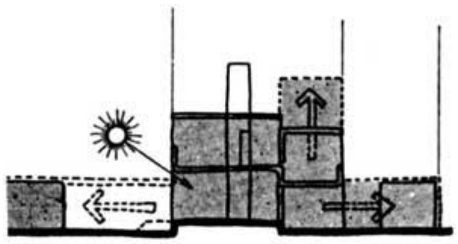
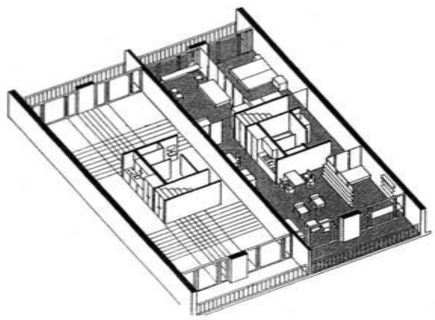
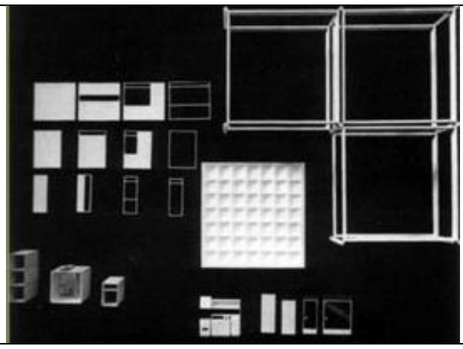
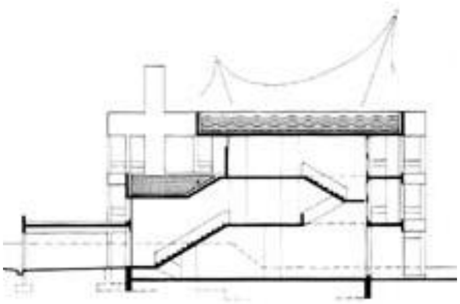
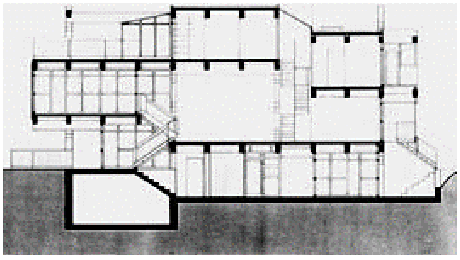
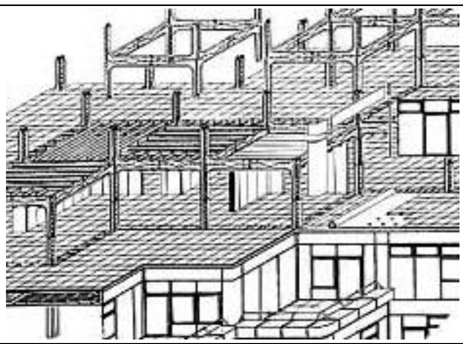
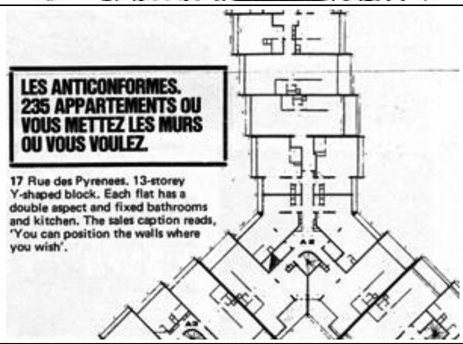
FIGURES	FACTS
	**Movable boxes, Yona Friedman, 1949** The project is inspired to the war experience of sharing the same room with one or more families dividing it using furniture. The structure could be used for houses of one or more floors, and it consists of two party walls and two end walls, with windows, doors and a roof. This external shell delimits a blank space, while the inhabitants can determine the interior layout. All sanitary and kitchen units and closet partitions are lightweight boxes that can be positioned by inhabitants as desired or needed.
	**Meudon, Jean Prouvè, France, 1950** The fourteen standardised houses are designed as a kit of parts with interchangeable panels. The development continues the study about the use of aluminium as primary building materials, finally in a sub-urban context. The houses are intended for low-income transitory residents who, in the post-war economy, simply needed modest houses. Raised above the ground through a masonry basement for cooling purposes, each of the houses is composed of a central aluminium bay and a complete open plan. The construction of each single house required three days.
	**Jarnbrott Experimental housing, Tage and Anders William-Olsson, Sweden 1953** The two main features of the five-storey building are the open plan and the modular infill. The fixed elements of the plan are a bathroom and a kitchen unit. A single column is located in the middle of an otherwise open space. All partitions are made with modular system of demountable panels with open joints. Prospective occupants were shown suggestions for interior layout, which they could determine before they moved and also later, over time.
	**Single-space house for four people, Gio Ponti, Italy 1957** This project develops the idea of a single space surrounded by the essential minimum of services, pushed to the opposite sides of a single large space. A series of sections of wall and moveable panels allow the creation of different connections between different areas. The flexibility of the use depends upon the user: through the positioning of walls and moveable panels, areas can be connected as well as isolated, though never acoustically. The openness of the apartment has to be shared by all the inhabitants.

Table 5.1
1945-1950s: the “baby boomers” and the post-war reconstruction.

FIGURES	FACTS
	**Kallebäck Experimental Housing, Erik Friberger, Sweden, 1960** The housing development is a shelving unit that provides individual sites for single detached houses, in which the front of the "shelf" forms the edge of balconies. Each house is set on a concrete floor plate, and can have its own facade treatment, floor plan and roof. Two people are needed for changing parts: one to hold the element, another one to fix it. The shelves should have been filled over time, but the scheme was so popular that the plots were sold out from the beginning.
	**The adaptable house, Development Group of the MHLG, UK, 1962** This project focuses on the importance of adaptability to future needs. The project considers the stages in the family's life cycle and their expression in space, with seven different stages over a period of fifty years starting with marriage, the arrival of two children within five years, another child within the next 5 years, the growing up of all children, their leaving the house gradually up until the final stage from year 35 when the couple is on their own again.
	**Extendible houses, J.H. van den Broek, J.B. Bakema, The Netherlands 1963** On an elongated plot of land, the architects propose a narrow house with a small front garden, a kitchen and a combined dining and living room on the ground floor. This small core unit is designed to be expanded horizontally to the front and back, and vertically upwards. Towards the front, on the site of the front yard, an additional room can be built, which might be a garage, a small shop or a guest room. Towards the back, the rear garden can transform into a series of rooms organized around a courtyard.
	**Neuwil, Metron-Architekten AG, Switzerland, 1962-65** The staircase is part of a freestanding core that also contains the bathroom and a kitchen. To each side of this core, spaces can be subdivided within the constraints of a grid, using any of the five types of ready-made wall panels, stored in a common room. The overall size of the apartment cannot change but the size and number of rooms can be changed with great ease. A users' manual was prepared to assist tenants in the process, depicting life-cycle scenarios and their spatial implications, together with instructions to assemble wall panels.
	**E.C.C.S. Steel Housing, J.H. van den Broek, J.B. Bakema, Netherlands, 1967** The solution combines prefabricated systems with a repetitive module that can deployed over the time, both vertically and horizontally. The basic module can be self-sufficient or can be combined with any other number of modules. The module is then filled in with a secondary system of floor and ceiling panels, a series of differently sized wall and window elements, prefabricated bathroom pods, cupboards and kitchen units.

	**Wohnhaus Kronsberger Stasse, Bernhard Binder and Stefan Polonyi, Germany, 1969** This building provides the capacity for change through its form of construction, which allows the expansion and contraction of individual dwellings within the same structure. The building is designed on a grid using a reinforced concrete frame. A central staircase divides the building in two halves, each of which is unobstructed, apart from a few columns and a service duct. The architects show a variety of possible layouts testing their design for long-term flexibility within a changing market situation.
	**Diagoon Houses, Architectuurstudio Herman Hertzberger, Netherlands, 1971** The idea is of the "incomplete building", meaning that a basic frame leaves space for the personalised interpretation of the user in terms of number of rooms, positioning and uses. The occupants are able to decide how to divide the space and live in it. If the composition of the family changes, the house can be adjusted and, to a certain extent, enlarged. There are two fixed cores, one contains the staircase and the other one kitchen and bathroom on different levels, with several half-storey levels attached.
	**Wohnanlage Genter Strasse, Otto Steidle and partner, Germany, 1972** All buildings of the housing development are built with a skeleton of reinforced concrete with the same spatial possibilities, but they all differ in their detailed design and in terms of architectural expression. Thanks to the clear distinction between loadbearing and non-loadbearing elements, walls within the frame can be altered easily to be adapted to users' needs and wants. Over the last 30 years, volume, interiors, and users have changed considerably.
	**Metastadt, Metastadt-Planungsgesellschaft mbH, Germany, 1974** The system provides a vision for flexible urbanism, a space plan capable of unlimited horizontal and vertical growth. The various elements of the system, such as the loadbearing structure, non-loadbearing panels, and services are independent. The space frame structure itself is bolted to allow easy assembly and disassembly. The facade panels are based on a small set of interchangeable parts with a vertical and horizontal module held in position by "push buttons".
	**Les Anticonformes, Les Frères Arsène-Henry, France, 1975** Buyers are offered open plan units that can be subdivided on a grid basis with a given system of partition walls. The sale price is fixed on an area basis, independently from the quantities of partitions, doors or cupboards selected by purchaser. Only bathroom and kitchen are fixed in plan. The position of electrical sockets, set as a grid in the floor, is also changeable, so each alteration in layout or movement of a partition wall does not require a complete re-wiring of the apartment.

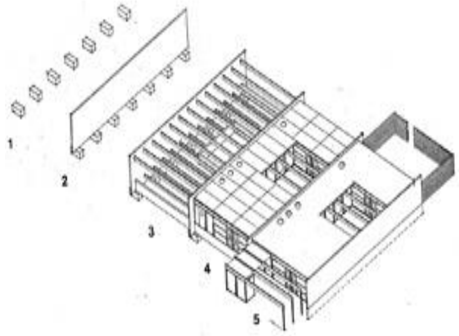
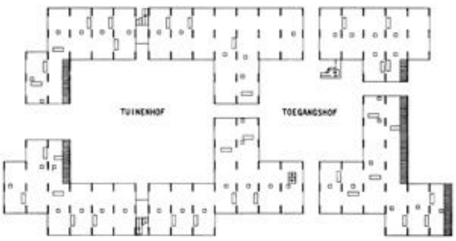
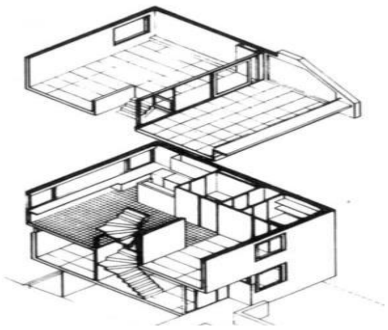
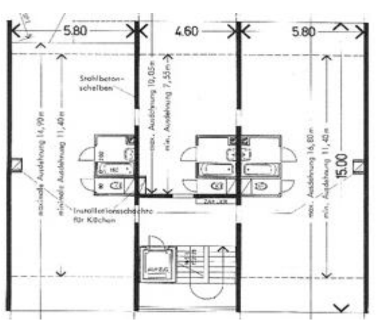
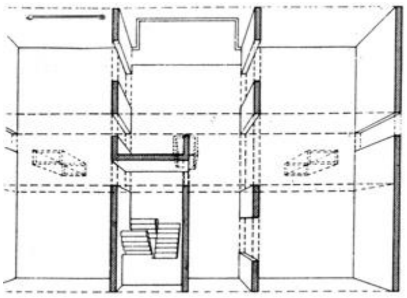
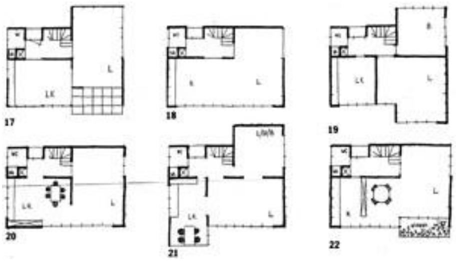
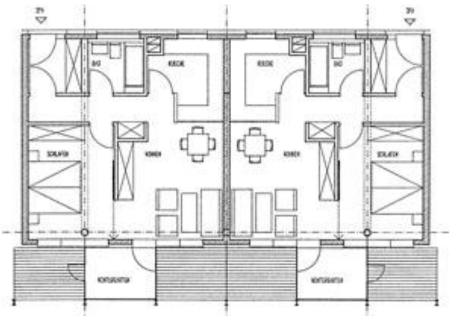
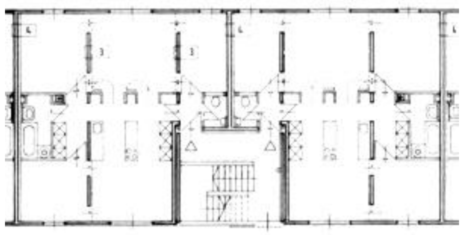
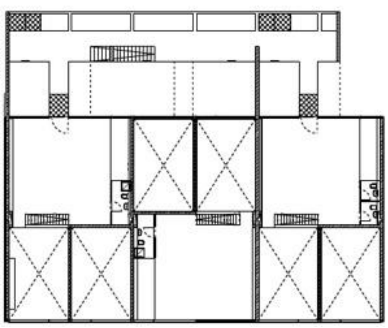
	**Flexibo, Flaellestegnestuen, Denmark, 1976** The dwellings are partially designed, and often also partially built by the residents. The principle of layers defines the design: parallel walls of concrete provide the dividing perimeter of each house. After these walls are placed, flooring elements are laid on concrete joists, roof and deck elements on timber beams. The facades are closed with light elements. Whilst the basic frame of prefabricated concrete and laminated timber cannot be altered, the interior is based on a modular wall system, which can be reconfigured by inhabitants.
	**Molenvliet, Frans van der Werf, Werkgroep KOKON, Nethelands, 1977** The process of user involvement in terms of decision-making is based on the overall plan of a neighbourhood, the negotiation of built areas in the form of open spaces and building zones, planning of the support structure, designing the individual infill, which determine the floor plans and finishing. The support structure is a concrete frame, allowing free subdivision into apartments ranging in size. The empty support plan was gradually filled through discussions with the occupants.
	**Alexandra road, Neave Brown, UK, 1969-78** Flexible housing is not only achieved through open space or loose planning, which demands a lot of space not available in public housing. The architect believes in the understanding of how people may use a house over time, and then designs for those scenarios. Flexibility here is about explicitness, a freedom achieved through prescription of specific solutions that can be adapted to changing social use. The project is based around the notion of zones, with a ground floor that can be cut off and handed over to a different use or user.
	**Adelaide Road Estate, Greater London Concil, UK, 1979** The process firstly involves the construction of a structural shell, which consists of loadbearing brick cross-walls and cast-in-place concrete floors, as well as primary electrical and mechanical service points. At strategic positions, these walls and floors have "soft zones", which can be opened up to allow both vertical and horizontal combination between floors or bays. The infill kits consist of vertical ducts, partitions, doors, cupboards, bathrooms and WCs. Tenants were given two weeks to design their own interiors. Architects refined these designs, advised on amenities and costs.

Table 5.2

1960s-1970s: house expansion and standardised affordable mass housing.

FIGURES	FACTS
	**Feßtgasse Housing, Ottokar Uhl, Austria, 1980** The project aims at involving maximum tenants' participation. The building consists of a three-bay structure of loadbearing cross-walls with a central staircase every three apartments The only fixed elements are toilets and bathrooms, located against the cross-walls, and a service duct which indicates the position of the kitchen, but not its final layout. Openings in cross-walls serve as access doors or connection between rooms in dwellings occupying more than one bay. The positions of the rear facades are not fixed, allowing to vary the size of the apartments.

	**Flexibele woningbouw, Volkshuisvesting Rotterdam, Netherlands, 1984** The four-storey buildings are structured on a series of cross-walls, made up of fin segments with gaps that can be connected to create close rooms and spaces. Each building is divided into zones: a central internal zone with horizontal circulation and services, and two zones of rooms along the outer sides of the building. The resulting space is only limited by the position of the vertical circulation and the fixed vertical service ducts, with the possibility to create bigger rooms.
	**Honor Oak Park, Walter Segal, Jon Broome and self-builders, UK, 1987** The system was designed to empower self-builders to take control of both the design and construction of their homes. They were supplied with basic plans and sections and a typewritten specification describing the construction sequence while they could adapt the layouts to their own purpose. The flexibility is given by lightweight dry and demountable systems with a modular frame and standard panel sizes. Improvisation is possible within a set of rules so whilst the exteriors are relatively uniform, no two floor plans are the same.
	**Brandhöfchen, Kramm + Strigl, Germany, 1995** The scheme is organised in five east-west oriented four-storey rows of houses. The plan is based on a regular structural grid system, with kitchens, bathrooms and entrance along the north facing side of the building and a series of spatially equal rooms towards the south. The only load bearing elements are beams and columns, meaning that even party walls can be removed to combine two smaller units into one large unit. Small service cores are located on each grid line along the north facade, allowing for a range of possible connections.
	**Housing Graz-Straßgang, Riegeler Riewe Architects, Austria, 1994** The building is organised on three levels with each staircases serving two apartments per floor. The size of apartments ranges from smaller units to larger units. Each unit has a central wide zone that can be divided in various ways, acting as an expanded hallway, gathering various activities whilst allowing multiple connections to the outer rooms. Rooms, which have no predetermined use, can be connected or disconnected to each other by means of foldable and/or sliding walls on a daily basis or, else, be fixed permanently.
	**Kölner Brett, Brandlhuber and Kniess, Germany, 1999** The volume consists of twelve identical spatial modules, partially on two levels. The “neutral” modules provide a spatial indeterminacy typical of industrial or commercial buildings, and they can be personalised through the use defined by their inhabitants, who are handed over the raw shell of their space. Each unit was sold as raw space. Also bathroom units are determined at a later stage by the users, which reduces the price for a unit, but also enabled individual control over spatial and functional arrangements.

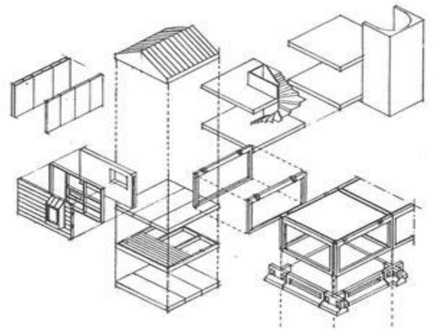
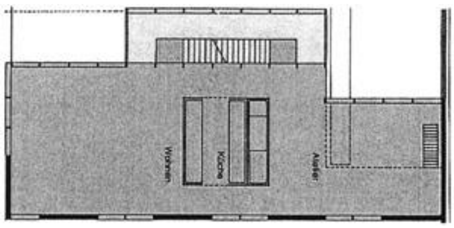
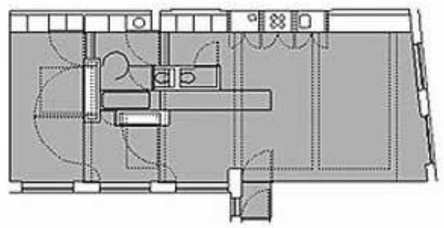
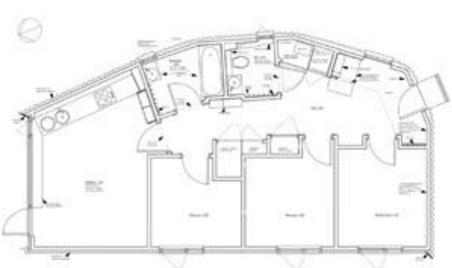
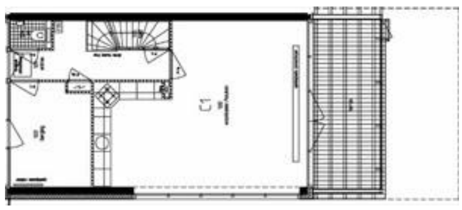
	**Ålekistevej, Hvidt and Mølgaard, Denmark, 1988** The four-storey scheme accommodates a supermarket on the ground floor and 18 apartments, some of which are arranged over two storeys. The structural frame is a concrete column and beam system with all dry finished joints. Flexibility is provided by the modularity of the elements and their mountability. Horizontal conduits and pipes lie in the floor/ceiling elements and vertical shafts within the layer of the facade. Facade and deck elements can be removed enabling low cost and relatively easy adjustments in accordance to changing housing needs.
	**Atelierhaus Sigle, Architekten Linie 4, Germany, 1998** The timber structure of this building combines residential functions with an artist's studio. The loadbearing elements are placed on a regular grid along the edges of the building. Timber beams span across the width of the building so that no further structural columns interrupt the floor area. The resulting open space can be divided freely. Short wall panels and furniture units, none of which touches the perimeter walls, can articulate rooms. Sliding doors at the end of each of these partitions can close relationships between rooms or enable them.
	**The Transformable Apartment, Mark Guard Architects, UK, 1996** It is a contemporary exploration of the theme of foldable beds and sliding doors. The unit is accessed slightly off-centre along one of the long sides of the floor plan. A built-in wall, containing the kitchen, kitchen storage, drying cupboards, and wardrobes occupies the entire wall opposite to the entrance. Three freestanding modules contain the elements through which the space can be changed. One module contains the WC, the other two contain foldable down beds and sliding doors.

Table 5.3

1980s-1990s: Renovation, revitalisation and urban sprawl.

FIGURES	FACTS
	**Silvertown, Ash Sakula, UK, 2004** In this project, the circulation space is the focus point: the hall, renamed "sorting zone", and the kitchen are the most important parts of the plan. The "sorting zone" is a polyvalent room, suited to many different functions during the day or during various years of occupation. The kitchen is also a living, meeting and children's room. Both rooms focus on the communal aspect of a dwelling and promote a highly sociable concept of the living space. The three remaining rooms are reduced down to a minimum and can be used in a variety of ways.
	**Flexible Housing in Almere, UN Studio, Netherlands, 2001** Each house consists of two basic modules: the upper volume is shifted in relation to the lower one, creating a distinct entrance zone on the ground floor and a terrace for the first floor. To extend this basic volume it is possible to add a further half module onto the top of the upper volume or a prefabricated box in different points. Inside, kitchens, bathrooms and stairs are not predetermined but kept as free as possible. Future occupants are integrated into the planning process, being able to determine the position rooms and of partition walls.

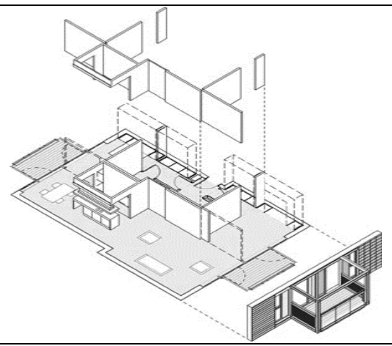
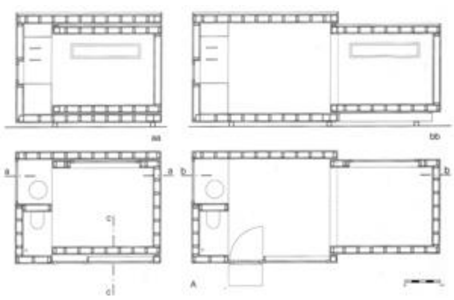
	**Greenwich Millennium Village (II), Proctor and Matthews Architects, UK, 2001** The residential units are designed to be adaptable to different lifestyles and users. The apartments have a clever plan that allows a variety of layouts with two central service cores divided by a small corridor. Around the edge there is a sequence of spaces that can be divided up with walls that slide into recesses of the service cores. These acoustically isolating walls can be closed permanently or can be temporarily pushed back in order to create a more open plan to use in a variety of ways.
	**Fred, Kaufmann 96, Austria, 2000** Fred is one of the few projects to explore the idea of building in expandability. It is a timber container consisting of two boxes: one outer box and one, slightly smaller, that slides inside the bigger one. Kitchen and bathroom, a small room with WC, and integrated shower, are located in the fixed part, with the remaining area open for interpretation. Delivered on the back of a lorry, Fred can be assembled within two hours. Four steel feet support the larger outer volume and two further feet carry two bearers on which the sliding box can rest.

Table 5.4
2000s-present: Urban sustainability and housing affordability.

The study of the state of the art led to the definition of families of strategies to obtain flexibility and to respond to the need of the users in a long time and cost effective method.

First strategy: plug-in
This strategy describes the possibility given to an occupant to expand or change a space by "plugging-in" a new part increasing the possibility of usage.
The modification can involve both horizontal and the vertical planes, and it should be planned already during the design phase, in order to define the best plan layout to accommodate additional units.
Ideally, the new spaces should be accessible using the same accessibility system, without interferences with the natural illumination.
A key issue is that the construction should not cause disruptions to the existing dwelling, blending into it.
This strategy offers many alternatives and opportunities for the current and future inhabitants, increasing the marketability of the property.

Second strategy: sum and split
The technique considers the possibility to connect two individual adjacent spaces to form a single larger space, and vice versa. Multiple dwellings must be considered within this design process, in order to avoid dimensional limits.
Other important considerations are connected to accessibility, to the provision of openings performing in different plan configurations, and to the design of services able to minimize the expenses.
This approach is a convenient long-term strategy that provides flexibility and a variety of rental opportunities for different family units.

Third strategy: shared room
Two adjacent dwellings can also share a non-specific room, negotiating its use, ownership and responsibility over the time in relation to the actual needs.

This room is often a larger space that accommodates a small bathroom and kitchen, to be used separately or partially joined to the principal unit, as a granny flat, home office, or a studio.
The disadvantage connected with this strategy is the possibility of conflicts between the two tenants, if both require the extra space or none of them needs.

Fourth strategy: movable walls
In this case, the space can be quickly and easily arranged and re-configured for new functions, on a daily basis or in a long-term vision.
The design of the elements must allow fast and easy changes: panels must be designed to disappear in open configuration and they do not have to interact with any structural elements.
It is necessary to consider the practicability of the solution because moving and sliding of wall panels require considerations, such as to the placement and location of furniture within the space, and whether or not this furniture is required to be moved to suit all the possible spatial configurations.

Fifth strategy: folding
The method allows the inhabitant to change the use of a room on a daily basis, hiding the elements of the furniture when not needed.
A successful design considers the folding elements as integrated completely in the dwelling, disappearing and appearing giving in any case a coherent layout to the space. In some cases, the folding element can be fixed but with multiple use over the day and over the time.
This technique is particularly efficient in very small dwellings.

Sixth strategy: unfinished space
In this space, the use has not been fully determined by the designer and can be defined by the inhabitants at any later date.
This space owns the potentialities for different possibilities, so the designer must think of the possible ways in which the space may be modified, and then designing the space accordingly.

Seventh strategy: neutral space
The strategy concerns providing unlabelled rooms. The occupants can decide the most beneficial use of each space.
The main strategy of functionally neutral rooms is to provide a number of equally sized rooms off a central hall or circulation space with the services possibly being allocated to the smaller areas.
By removing the hierarchical order contained in the labelling of rooms each space becomes an independent entity which can be used according to the needs of the occupants, inevitably changing over time.
An added benefit connected to functionally neutral rooms is that the same housing unit can be occupied by a variety of different user groups.

5.4 Self-building and progressive construction

Some author (Forty, 2000) argues that flexibility can become part of a wider regime of control for architects, which believe in this way to influence the building also in the future.
On the contrary, Friedman claims that architectural knowledge cannot be the exclusive property of professionals and specialists, and suggests providing people with writing guides or manuals, which explain

topics and illustrate basic skills, related to architecture and urban planning, in clear and simple terms (Friedman, 1960).

In all cases, the basic question is simple: what should be decided by the group, and what should be decided by the individual? This is the question Habraken framed in 1960 (Habraken, 1972) and which open building seeks to address in various ways.

This formulation is the open building approach – distinguishing the decisions (and systems) made for the public from the decisions (and products) made in respect to the individual occupant. This means - potentially – two distinct markets and two distinct processes, not in conflict but in coordination (Kendall, 2004).

This notion of empowerment is also a central feature of participatory design processes. Generally, buildings designed to be adaptable over time, will also lend themselves to user participation during the design process (Schneider & Till, 2005).

The extreme result of this is the "self-build" practice, which can vary form doing undertaking the actual building work to contracting out all the work to an architect or building package company.

People build individual homes for all sorts of reasons, but mainly because they want to create something tailored to their family's unique requirements; or something architecturally appealing in all manner of styles; or because they want to live in a home that they might not be able to afford on the open market. There is something uniquely rewarding about building a home for you and your family, it harks back to the most basic of human instincts. Nowadays, however, self-build homes are not just about shelter and security, they are about expressing yourself and your lifestyle. For many, self-build is a chance to create the life they have always dreamed of (Giddens, 1991).

Self-builders create their homes through a variety of methods - and very few actually build it entirely themselves. The majority employ an architect to come up with the design of the new home and contract a builder to construct it; others use so-called 'package' companies to provide a one-stop solution. Many others find themselves managing building sites and dealing directly with planners, tradespeople and materials suppliers.

Self-build in its wider meaning is an ordinary practice in many developing countries. It is also common among certain religious communities or subcultures. Usually eco-villages are realized through self-building techniques. In most developed countries self-build is somehow regulated by the public administration, while in developing countries self-build process in sometimes supported by NGOs or international organizations.

Over the years, self-builders have been at the forefront of advances in house design and technology, being responsible for the dramatic uptake in recent years in eco-features such as solar power and heat pumps; underfloor heating; open plan design and smart home technology. These features take many years to filter through to commercial housing developments.

Another important concept connected to this topic is the "progressive architecture".

The home is for its nature an "incomplete project", subjected to change whether in reality or in the imagination of its inhabitants (Pink, 2004).

John Weeks was the first architect to defend the "unfinished" solution on the ground that none of the big institutions are able to predict the changes that the building might require after it is taken in use. The idea of an "indeterminate architecture" requires the clear and logical design of the entrance and principal routes, and each building could readily expand its services, then any adaptation, extension or rebuilding could be undertaken without disturbing the rest. It was a model for flexibility within a logical plan used for hospital and airports.

The idea of "indeterminate architecture" can be applied to many different contexts, such as to the provision of affordable housing and it can be efficiently used in coordination with self-building practices.

The project of Quinta Monroy in Chile, experiment the idea of "unfinished" housing and self-building within a complex socio-economic context.

The necessity was to create a settlement for 100 families in the same 5000 m2 site that they have illegally occupied for the last 30 years, located in the very centre of Iquique, a city in the Chilean desert.
The Housing Policy provides only a US$ 7500 subsidy to pay for the land, the infrastructure and the architecture, a value that for the current Chilean building industry would have provided 30 m2 of built space for each family.
The first idea was to look at the economic problem from another point of view, so instead of thinking about the best possible US$ 7500 object to be multiplied a 100 times, to scale of the best possible US$ 750000 building capable of accommodating 100 families and their expansions.
This without renouncing to the central location of the site, which, despite the greater cost for the land, was fundamental for the success of the proposal. Social housing indeed tends to look for land that costs as little as possible, normally far away from the opportunities of work, education, transportation and health that cities offer. This way of operating has tended to localize social housing in an impoverished urban sprawl, creating belts of resentment, social conflict and inequity.
Another important point was to interpret social housing as an investment and not only as an expense, to make the initial subsidy increasing its value over time. This was achieved providing enough density, (but without overcrowding), in order to be able to pay the site to maintain the network of opportunities that the city offered and therefore to strengthen the family economy; on the other hand, good location is the key to increase a property value.
The second strategy was the provision of a physical space for the expansion of the family, which has proved to be a key issue in the economical take off of a poor family.
So instead a designing a small house of 30 m2, it was decided to provide the skeleton to build a middle-income house of 72 m2, of which the 50% will be eventually and progressively self-built.
The idea is to create a building porous enough to allow each unit to expand within its structure. The initial building must therefore provide a supporting, (rather than a constraining) framework in order to avoid any negative effects of self-construction on the urban environment over time, but also to facilitate the expansion process. The architects provide the skeleton, and leaves the rest to residents.

5.5 Discussion

Probably the best-known constructional principle to facilitate flexibility in housing is that of Habraken, whose theory of ‘supports’ was developed in opposition to prevailing conditions in the Dutch housing sector of the 1960s, as well as to enable his ideas of user participation.
Habraken, and the current Open Building movement, emphasise the use of modern construction techniques and prefabricated elements (factory-produced columns, beams and floor elements), but also the separation of base building, infill systems and subsystems, and manufacture and design for ease of assembly and disassembly (Kendall & Teicher, 2010).
While Open Building today typically presents a highly technicised building method, flexibility can also be achieved through simple building materials such as timber, as exemplified in the work of Walter Segal.
As with Habraken, we see in Segal the use of a flexible technical system as a means to achieve a ‘flexible’ social end, with his seminal buildings of the 1960s founded first on a belief in the empowerment of the lay self-builder.
The least researched area of flexible housing is the financial side. Sense tells us that flexibility is more economic in the long term because obsolescence of housing stock is limited, but there is little quantitative data to substantiate this argument (Schneider & Till, 2005).

As the cost of housing and construction prices increase, prefabricated buildings hold the promise of greater economy than their site built counterparts enhancing also quality control.
Even if Metabolism buildings were not built for economy per se, the 100 sq. ft. capsules used by Kurokawa in the Nakagin Capsule Tower were said to be roughly the price of a Toyota Corolla (Russel, 2008).
At the same time, the perception of affordability in prefabricated buildings has come with the negative perception of inferior quality. The only way to get over this problem is to show that implementing flexibility adds value to the property and so it can command a higher price for little, if any, extra investment (Schneider & Till, 2005).
Architecture has to position itself in such a way that it is not bound to react to a certain event, but is can also create a premises, an initial framework on its own. Escaping the reductive assignment of being the problem-solver, architecture assumes the capacity to pose problems, which are relevant for intervention (Ruby, 2005).

6. DESIGN TOOLKIT: STRUCTURE, TECHNOLOGY, AND CONSTRUCTION

6.1 Introduction

The housing stock of the European cities needs to be studied and understood, in order to define the best retrofit strategy.

The period between the two Wars and, even more, the one started after the Second World War, is of great importance for the debate around urban renovation because it was the key point in the development of the residential building stock. In those years, the problem of housing was at the core of the most innovative experimentations (Le Corbusier, 1931).

The great architects of the early 20th Century tried to suggest solutions to the lack of technical, functional and aesthetical performances of the social housing stock, using the new tools of the period, such as steel, concrete, plate glass, and mass production (Larson et al., 2004).

Nonetheless, these visionary experimentations resulted in monotone and impersonal mass housing, enlightening the failure in taking advantage of industrialized processes in the construction sector (Herbert, 1984), producing instead suburban sprawl and low quality buildings.

The question about designing “large projects without imposing uniformity and rigidity” is today still open, and how big projects can “do justice to the small scale” is still the main issue to address (Habraken, 1987).

The possibility to exploit industrial construction methods, such as pre-assemblage capabilities and delivering to the site is seen as a possible horizon of development, because, even if the majority of houses are still built in traditional materials by conventional methods of construction, industrialized processes are being used with greater success in other construction spheres.

Apparently, prefabricated houses have earned over the years the reputation of being cheap and ugly, since aesthetics, comfort and quality have been sacrificed for the sake of economy and fast production

This happened because most producers fail to consider and acknowledge the unique factors operating when human beings and environment are involved. This short-sighted practice is rapidly transforming a vivid and mixed landscape into a homogeneous mass lacking quality and distinction (Kendall, 2004).

On the other hand, the degree of control afforded by the factory manufacturing, the use of standardized components, and the dramatically abbreviated constructions times still make prefabricated housing an appealing option for many builders, developers and homebuyers. Industrialized construction techniques increase efficiency, reduce costs, save materials and labour resources, providing a cost-effective solution to cope with the growing demand for housing.

In the near future, the construction industry will face additional challenges related to the issues of global warming and shortage of fossil energy. Society will ask for a zero waste and zero impacts. Until recently, the construction sector contributed to environmental and urban sustainability by building energy-efficient buildings and using sustainable materials: this will no longer be sufficient. The industry will need to justify material and energy use and waste production during construction, during the use and at the time of demolition, considering the possibility of re-cycling materials and re-manufacturing building parts (van Nederveen et al., 2009).

The theme becomes even more urgent when we speak about the retrofit of the existing heritage, with additional challenges to engineers in selecting technically, economically and socially acceptable solutions of intervention (Cheung et al., 2000).
Past researches of McCleary (1983) suggested finding a solution in the use of technology, intended as "the discourse between societies and their natural environment in the production of the built world ".
Planned retrofit projects will consider the continued use of emerging technologies, since the use of progressively innovative technologies results to be far less intrusive to building occupants and offered savings in construction cost.
In addition, since no two buildings are the same, the challenge is to select, time after time, technically, economically and socially acceptable solutions.
Beside that, a common problem among social housing buildings is that most of them were built under far lower energy and sustainability standards.
Only after the oil crisis of the 1970s, indeed, the increasing awareness of fossil fuels deficiency brought concerns on the energy efficiency of the building stock, resulting in the first legislation related to envelopes, insulation and materials (Balaras et al., 2005). Consequently, the considerable share of the housing stock produced before this period lacks of technical and functional performance connected to energy efficiency. We are speaking about the 70% of the existing buildings are over 30 years old and about 35% are more than 50 years old.
The common answer to the increasing requirements for lower energy use, high living standards and seismic safety is the retrofit of the existing stock.
This chapter presents the considerations connected with the structural design of a retrofit intervention, the available technologies and materials, and their properties in order to resist to seismic loading.

6.2 Designing flexibility: structure, technology and construction

If one method of achieving flexibility in housing is through the appropriate design of the plan, another is through the deployment of technology, considered as the complex of construction techniques, structural solutions, and servicing strategies (Till & Schneider, 2005).
Clearly, these two approaches are not mutually exclusive but usually they are used in combination to obtain a flexible residential project.
Experiences have shown a significant correlation between the selection of a construction technique and the degree of flexibility achieved, so that most of the successful renovation projects resulted to rely on techniques able to allow additional interventions over the time with simple processes, in strong opposition with the standard practice, needing of specialised and multiple skills for any update (Schneider & Till, 2005).
Simple and robust construction techniques based on lightness and flexibility principles, with the possibility to obtain reversible and removable interventions, are today the most convenient way to apply modifications to an existing construction.
A means to obtain flexibility is the selection of dry-construction systems, which reduce time and costs of construction, with less environmental impacts during construction and at the end of the useful life of the building organism, thanks to the high percentage of recovery of the individual components, assembled mechanically. The reversibility of lightweight dry construction processes confers also a greater life span to the building, in relation to the changing needs of the inhabitants (Scuderi, 2015).
These techniques require every single part to perform a function with well-defined and measurable standards, being part of the structure, of the envelope or of the internal partitions. The way in which these elements come into mutual relationship helps to define the constructive system of a building.

Every component seeks for optimization, enhancing the lightness and the simplicity of the structure as a whole and exploiting the full potential of technologies, materials and design (Scuderi, 2015).
A good structure is the one able to respond to functional requirements balancing the efficiency and economy of the design, reducing the amount of material and the constructive complexity at the same time improving quality and optimization (Dooley, 2004).
The new technical and technological knowledge facilitates the management and monitoring of more complex architectures in every phase of their design process, passing by material analysis, external interactions (environmental and human) and form finding. Nowadays, these tools allow moving away from the past uniformity and rigidity, and design skills can then representing the weakest element of a project (Habraken, 1987).
The actual problem arises when the emphasis shifts to the technical and constructional aspects of social housing, and away from the more socially grounded implications of flexibility. When techniques becomes an obsession, then the technology becomes an end instead of a mean to reach an end (Till & Schneider, 2005). In this way, the technologies of flexibility lead to constructions where the technical aspects overrides issues of design and social occupation.
The solution is instead to use technology to create a framework for flexible housing to develop, abandoning the idea of a strict determinism and allowing a certain degree of “controlled freedom”.
This strategy exploits technology to create structural systems, in form of expressed frames or grid structures, able to accept further and progressive changes. Loadbearing or solid internal partitions should be reduced, such as the roof, which could close the possibility of future expansion. These schemes require service core, accessible and adaptable for different plant reconfigurations, during which user activities should continue, preferably undisturbed.
The method can be used in multi-family residential and mixed-use projects – in new construction or for the retrofit of existing buildings. This is particularly advantageous in large-scale real estate interventions, where simultaneous design of base building and user level is impracticable.
The basic principle is again the division between structural fixed elements, with a long-life span, and movable components with a shorter life cycle.
Social trends towards individualization of use make functional specification increasingly personalized, and greater complexity and variety on the demand side is stimulating the introduction of architectural components with shorter use-life, such as partitioning, ceilings, bathroom, and kitchen facilities.
Systems and components that are not any longer useful for one building may be re-installed in another building. At the same time, if systems or components cannot be re-used as such, the materials from which they are made can be disassembled and reused for the production of new components or systems. The latter principle complies with the cradle-to-cradle concept such as described by McDonough and Braungart (2010). Furthermore, it forms an extension of the concept of building manufacturing towards building re-manufacturing. This principle implies a structural design that considers more carefully the materials used and the way in which components are joined, to allow reusability and disassembly.
If “static” buildings require high and risky investments, the components and materials that constitute an adaptive building have an extended lifetime that may be substantially longer than any individual building. Hence, the risks for investors decrease.
In this vision, Larson et al. (2004) developed a new and more responsive model for housing supply, based on new technologies and design strategies. Within this model developers work to offer tailored solutions to individuals, architects create thousands of unique environments, manufacturers become suppliers of components, builders become installers and, finally, users become designers of their own unique living space. Contrary to the common belief, there is not necessarily a conflict between efficient production and variety of forms. In fact, the variety might be the logical outcome of efficient production (Habraken, 1987).

There is a social responsibility for prefabricate housing industry to create an interesting and vibrant environment, where the necessity of affordability is not anymore an acceptable excuse to provide inappropriate solutions.
Industrial construction has come a long way over the last 50, anyway, numerous studies have shown that, if compared to others industries, it still lacks of productivity (Egan, 1998) due to the repetition of the same mistakes across projects (Josephson & Hammarlund, 1999). This phenomenon emerge from the lack of practices and technologies for accumulation of knowledge. There simply does not exist organizational learning processes, where companies systematically learn from the experiences they gain from their projects. This implies that there does not exist a platform for a continuous innovation.
One of the strategies to overcome this situation has been a strong focus on reapplying industrialized ways of working in the building industry – combined with an emphasis on radical innovation as a tool for implementing the required change.
This has resulted in an extensive focus on new industrialization efforts in the building industry during the last years (van Nederveen et al., 2009), as we will see through the analyses of the following key examples.

Domino.21, ETSAM, 2004
Domino.21 is a research project developed at the Department of architectural projects of ETSAM, led by professor José Miguel Reyes and developed in coordination with many companies.
The proposal is a design to build collective and flexible housing, based on a catalogue of units built with compatible components of different brands and with industrial production processes.
This system of compatible components can be mounted inside an "open industrialization".
Domino.21 project suggests that housing can be seen as a product of the consumer market, where industrialization and technology allow differentiated responses and define a general system capable of reconciling different lifestyles and users (Vargas, 2007).
The result, presented at the CONSTRUCTEC 2004 within the IFEMA Exhibition Centre, was the construction of prefabricated collective dwellings, adaptable to the needs of the occupant and easy to assemble and change over time.
The building displays three floors with five homes for different users' typologies, characterized as following (González, 2005):

- Dwelling for three students: 85,5 m2 divided into three rooms, three bathrooms, a common room divisible for study and dining area, kitchen with office and terrace and an outdoor view-point.
- Dwelling for an artist: 31,5 m2 composed of a bathroom, a multifunctional room equipped as a kitchen and restroom, one internal viewpoint with garden
- Duplex for a family with two children: 65,5 m2 (surface first floor) with one bathroom, one kitchen, two external viewpoints and a multifunctional common area + 34,5 m2 (surface second floor) with bathroom, bedrooms, one internal viewpoint and a terrace.
- Dwelling for a retired couple + visits: 63 m2 with one bathroom, one kitchen, one restroom, one internal and one external viewpoints.
- Dwelling for a professional: 63 m2 with one bathroom, a common area transformable for work or rest, two internal viewpoints with gardens.

In addition, an exhibition hall and reception in the ground floor and a snack bar with a cover passage in the walk-on roof.
The building structure consists of a metal-wood mixed system so that the beams are attached to a modular metal structure, scaffold type. Wooden beams are attached to a modular metal structure, with 86 birch plywood boards in two sizes, plus laminated wood beams of 6.5 m span. All the facilities are below the wooden board. The pillars are anchored to the ground through a metal screw.

Once anchored beams and wooden boards, the lateral galleries form a permeable facade where independent modules can be inserted. These cubic units can be bedrooms, toilets or terraces.
The cabins are similar in size, but with different uses and finished using stainless steel, plywood, other elements derived from wood, glass, Plexiglas and sandwich panels, all materials produced in series. The cabins are grouped in kitchens, bathrooms, showers, terraces and balconies, and once installed can be exchanged quickly. Each cubicle is equipped with all necessary facilities that come factory assembled, connecting with the main building and the other cabins.
One of the great successes of the project was its assembly phase, which was carried out in record time and with an important means of coordination in just ten days.
One of the highlights of the proposed procedures is the use of 3D totally equipped components that are assembled on site by a "bull-telescopic", normally used for the collection and handling of goods under construction and loading docks. Then, the same procedure is used to change different areas of the dwelling.
All material components are approved and guaranteed by the manufacturers, and dry assembly allows easy replacement or exchange with each other.

IFD buildings, Ipostudio, 2004
The research project “IFD Buildings: Social-Technological-Commercial Process Model and Supporting Communication/Information System for Design and Delivery of Industrialised, Flexible, Durable and Demountable Buildings” aims at reducing the on-site works increasing prefabrication and preassembling procedures.
The approach includes the possibility to adapt the layouts to the user requirements, the possibility for the client to choose components, materials, and finishing from an IFD catalogue, the flexibility of layouts during the building lifespan, the possibility the recycle the component, the reduction of maintenance costs due to the easiness of disassembly, the repair and replacement of building and service components.
Industrialisation of the IFD buildings concerns the application of the industrial production model to the whole building process, from the design to the delivery stage.
A user-oriented building process involves the client in the design stage and gives him a set of available solutions which will be developed with the contribution of the other parties involved.
The IFD approach to the industrialisation does not aim to move the works from the building site to the industrial workshop; the concept is to introduce the manufacturing models in the building construction process.
Dry assembly technologies allow to remove totally or partially building and service components, favouring durability, adaptability and sustainability performances.
The temporariness characterizing IFD Building architecture and functions is the most important guarantee for the building to be durable, well maintained and answering to clients’ needs.
The design approach tries to develop technical solutions able to satisfy high-tech performance requirements, using a “soft” architectural design.
IFD House Construction System include three typologies of “macro-modules”: the Core, the Functional Modules, and the Shell.
The Core, a horizontal block articulated in two levels, is made-up of modular elements, which include horizontal and vertical circulations, service spaces and shafts for the service network. The Core is invariant of the system, delivered to the building site completely equipped and ready to be assembled performing also as a “guide element” to coordinate the assembly of the other components. Services spaces can change depending on user needs; besides basic services - kitchen and bathrooms-, many others spaces combinations can be chosen (hiding-places, working spaces, sauna bath, small gym, etc.).
Functional Modules are instead the variable parts of the system and they host the house’s functional spaces, changing their shape and dimension depending on the user’s needs. Functional Modules can be built using

different technologies, components and materials, and the interfaces with the Core is the only constraint to be considered. The solution chosen at the design stage can be modified and extended in time.
The Shell is made with a light steel frame covered with small panels that can be made up using different types of semi-finished products. Its characteristics enable the possibility to change position and volumes of Functional Modules in time, giving always a unitary perception.
The construction design of the variable parts is based on the “industrialised open systems” approach, with a given set of rules.
Building morphology and functional layouts have been studied to satisfy some specific types of users of whose profile has been defined considering trends and expectations of the European Countries potential market. IFD house’s users are singles and small or medium families, whit middle or high income.
A matrix of available combinations shows the basic layouts that the client can choose with the preferred materials and finishes. Each stage of the process can be done on line and the results can be checked using a virtual model, which allows visiting also the building interiors. The final solution will be provided with an instructions manual that illustrates all the possible variations, transformations and extension of spaces and services.

6.3 Structural and technological solutions

Current activity in the building industry is more concerned with refurbishment and rehabilitation of existing structures rather than with the creation of new structures, with reasons that include the considerable increase in the demand for buildings fitted with both structural and functional up-to-date features. In urban centres, there is also the need to preserve valuable constructions and artefacts from aging, natural hazards, and, in some cases, human misuse (Mazzolani & Mandara, 2002).
These problems require efficient and economic technological solution able to deal with an existing building as a system, composed of structural, architectural and functional features.
Today almost all types of industry have adopted automated processes to speed up, optimize and economize production, with the exception of the construction industry. Bridges and buildings are still cast on-site increasingly consequences regarding cost, quality and safety. Consequently, the construction industry is now facing the challenge of switching from pure on-site prototype production to fully industrialized and modularised made-to-measure prefabrication (Keller, 2010).
As an answer to these problems, new trends are presently gathering major importance in structural rehabilitation of existing buildings. The new practice is largely oriented to the use of advanced systems, materials and technologies to increase the structural capacity but also the efficiency of the construction.
Frame constructions, realized in timber, steel, aluminium, reinforced concrete or some combination of those, are gathering relevance in the recent years.
Framing is defined as the fitting together of elements to create a support and a shape for the building, using minimal structural materials to enclose a large area with minimal cost, while achieving a wide variety of architectural styles.
The individual members are prefabricated in a factory in relation to the specific needs of the site and of the construction, then delivered and efficiently assembled into the required frame.
When a framed structure needs to be used for an integrated retrofit program, then steel is an appealing option in terms of mechanical properties and characteristics, but also because of its applicability in connection with concrete, wood, bricks and stones.
The lightness given by the good strength to weight ratio, for instance, ease the transport and the construction, with less detrimental effects on the existing constructions due to additional loads.

The reversibility is certainly one of the most relevant properties for a retrofit intervention, and bolts can be used instead of welding to allow the release of the joints during and after the construction, such as when further modifications are needed. In these cases, if an increase in loading requirements occur, the structural steel elements can be individually strengthened or additional elements can be introduced.
Complementary structural components can easily be accommodated, such as walls and cladding, as well as other modularised elements, while the frame remains visible for ongoing inspection.
The good architectural aesthetics of the material is also supported by its convenience, due to the short construction period, which grants lower financing costs, better site utilization and earlier access for following trades. Steel is easy to find on the market in different forms and shapes and promotes cost savings throughout the whole project, thanks to the large unsupported spans, the smaller site footprint, the slender columns, resulting in maximising floor area. Costs are also predictable, which helps with a meaningful calculation of the investment and risk involved in the project.
The plastic behaviour of steel provides additional security in extreme loading situations, such as explosion, impact, terrorist attack and earthquake.
All these factors made the steel an appealing material for new constructions but also to intervene on the existing built heritage, providing modern and efficient solutions, thanks to the aesthetic, to the structural performances and to the prefabricated construction process.
Along with these well-known and diffused strategies, it is important to recognize how the introduction of new materials and technology can change the construction sector (Dooley, 2004) promoting innovations and new structural possibilities.
The implementation of new materials usually need of a phase of experimentation, during which they are simply substituted to traditional materials replacing their role a traditional structural form (Keller, 2010).
On the other hand, experience shows as only the development of new tailored structural concepts, able to exploit the full potentiality and properties of the new materials, can promote real innovation and economic benefits (Dooley, 2004).
In this optic, “smart materials”, able to respond to a stimulus with a predictable and fixed action, can define a new “smart structural systems” for retrofit interventions, able to adjust in relation to environmental inputs, increasing the levels of safety while at the same time prolonging the life span and serviceability of buildings and of structures (Otani et al., 2000).
Among those materials, shape memory alloys (SMA) have been studied for seismic protection (Castellano et al., 1997) also in relation to their superelasticity, an elastic and reversible response to an applied stress through a phase transformation between the austenitic and martensitic phases of a crystal.
A superelastic alloy deforms reversibly when mechanically loaded creating a stress-induced phase but when the load is removed, the new phase becomes unstable and the material regains its original shape without any need of a change in temperature. Shape memory alloys can grant a different range of responses in relation of different load conditions, always returning to their previous shape after the removal of even relatively high-applied strains.

6.4 Introduction to shape memory alloys (SMAs)

The structural rehabilitation of existing buildings is currently one of the most important tasks in civil engineering to ensure the safety and protections of human beings and building heritage.
Existing structures often lack of the necessary systems to overcome earthquakes, with insufficient dissipation during the event and consequent high level of damages with related risk for users.

This behaviour can be modified using devices for the passive dissipation of horizontal loads able to perform without technical supervision (Isalgue et al., 2006).
Recent researches on devices based on shape memory alloys components (SMADs) demonstrated their damping capacities due to the stress-induced martensitic transformation of the austenite phase (Song et al., 2006) and at the same time their recentring potential, thus inspiring new design possibilities (Dolce et al., 2000a).
Shape memory alloys are “smart materials” known for decades, but their use is still not widely diffuse in the civil engineering field (Janke et al., 2005).
On the other hand, many experimentations have been carried out in different fields exploiting the mechanical properties of the alloys, similar to biological materials (Duerig et al., 1999) also for the high durability and fatigue resistance. The achievements in quantity production of shape memory alloys, to date applied mainly in medical sciences, electrical and mechanical engineering can open to new applications in the field of civil engineering, specifically in the protection of constructions against seismic vibrations (Dolce et al., 2000a).
SMAs show the potential to eliminate some limitations involved in present technologies for seismic applications, allowing a broader field of action. This is achievable thanks to a combination of their performances and maintenance advantages, connected to a more reliable and constant behaviour over time.
In fact, they need no maintenance operations along the entire lifetime of the structure, even in the occurrence of several strong earthquakes.
A simple cost analysis estimates the initial costs of SMA-based systems to be comparable with respect to other systems currently used. As a consequence, passive systems based on SMA result, after all, more convenient than the systems based on traditional technologies, even without considering the important savings that can be obtained by introducing the new design concepts related to their re-centring features (Dolce et al., 2000b).
SMAs are usually binary or ternary metallic alloys that can be made of various metals (Copper, Zinc, Aluminium, Nickel, Titanium, Manganese, etc.) and characterized by crystallographic polymorphism.
Janke and colleagues (2005) listed 30 alloys with shape memory effect, however not all of them have the potential for being used in civil structures. This is due to the special mechanical properties required, the specific temperature conditions in civil structures and the costs involved.
The unique properties of SMAs are related to reversible martensitic phase transformations, that is, solid-to-solid diffusionless processes between a crystallographically more-ordered phase, austenite, and a crystallographically less-ordered phase, martensite. The latter may be present in single or multiple variants (Auricchio et al., 2006).
Typically, the austenite is stable at low stresses and high temperatures, while the martensite is stable at high stresses and at low temperatures (Duerig et al., 1999). The predominant crystal structure or phase in a polycrystalline metal depends on both stress and temperature and is controlled by both chemical composition and thermo-mechanical processing.
Accordingly, variations of the temperature and the stress levels can be imposed to trigger the transformation of one phase into another, and thus to control the mechanical response of the material (Bruno & Valente, 2002).
Each SMA differs in its mechanical properties. Such properties vary over a wider range, not only due to variation in chemical composition, but also due to the atomic arrangement in the martensite and austenite phase of the SMA that depends on the thermo-mechanical processing and heat treatment (Alam et al., 2007).
All of them have some peculiar properties in common, which are generally referred to as shape memory effect, the aptitude to recover the initial shape by heating, and superelasticity (or pseudoelasticity), the aptitude to recover the initial shape as soon as the external action is removed. These two effects occur, alternatively, depending on the phase, martensite or austenite, in which the alloy is stable at ambient temperature (Dolce et al., 2000b; Bruno & Valente, 2002).

In view of possible applications in the field of the passive control of vibrations, the most interesting features of SMAs are: the capability to undergo large strains (up to 8-10%) without damaging, the capability to recover the initial shape spontaneously upon unloading (superelasticity) or by heating after unloading (memory effect), a high corrosion resistance, for some alloys (Dolce et al., 2000a).
The superelastic behaviour of some SMAs exhibits good damping capacity as well, in a technical context, stands for the conversion of mechanical energy to thermal energy and therefore for the ability to reduce movements or vibrations of a structure.
Reason for this is the energy necessary for the phase transformations, which is responsible for the hysteresis in the stress-strain behaviour. The movement of austenite-martensite interfaces and interfaces between martensite variants contribute relevant to the damping effect. The area enclosed by the loading and unloading path of the stress-strain curve corresponds to the dissipated energy (Janke et al., 2005).
One main process for this is friction, either in the form of external friction between parts of a damping mechanism or in the form of internal friction of the material of a damping part.
As internal friction in SMAs is comparatively high, they have a very good damping capacity. The high internal friction is mainly based on two separate mechanisms. Whichever mechanism occurs is dependent on the stable phase state at ambient temperature and zero stress. Firstly, if martensite is the stable phase, we have the gradually reorientation of martensite variants when loaded transformation the above the yield stress. The area, enclosed by the stress-strain curve, is equivalent to the amount of the dissipated energy.
A self-heating of the material and thus a change in behaviour can be a problem for higher strain rates.
This is mainly dependent on the heat transfer to the environment and also on the shape and section of the shape memory parts. Cyclic loading can lead to a decrease on the upper plateau and increase the lower plateau of the stress-strain curve.
In the light of what said, it is easy to imagine the possible advantages of a seismic device based on SMAs: to exhibit, at the same time, an infinite lifetime, no problem of maintenance or substitution, even after several strong earthquakes, a good control of force and an exceptional re-centring capability (Dolce et al., 2000).
Due to the numerous influences on the material behaviour of SMAs, such as thermal situation, the loading rate, the strain amplitude, the number of cycles and the geometry of the shape memory parts, it is not easy to point out general values for the damping capacity (Janke et al., 2005).
Ozbulut and colleagues (2011) give an introduction to SMAs constitutive models to be exploited in seismic application and able to describe the complex behaviour of the materials while a review of the different models can be found in Auricchio (1995). Those models have been realized with two main approaches: microscopic or macroscopic. In general terms, microscopic modes exploit continuum mechanics to relate deformation, strain, and stress at particular points for a small material volume then combining the data with multiscale modelling. Macroscopic models, instead, try to describe the behaviour of SMAs at a macroscopic scale using phenomenology. Additionally some of those models rely heavily on thermodynamic principles, while others are developed by setting material constants of a model to match experimental data (Ozbulut et al., 2011).
Graesser and Cozzarelli (1991) developed one of the first model for a passive damping device starting from a one-dimensional model of hysteresis in this way being able to describe the two main effects of SMAs – shape memory effect and superelasticity – but not the influences caused by the loading and temperature conditions. This model was then developed to a further stage in order to consider the strain hardening behaviour of SMAs after phase transformation completion (Wilde et al., 2000) while Ren et al. (2008) made the model able to capture the strain-rate-dependent hysteretic behaviour of superelastic SMA wires. The proposed model divides the hysteresis loop into three parts and employs different parameters for each part.
Also Brinson (1993) proposed a one-dimensional constitutive model able to describe both shape memory and superelastic effects of SMAs. The formulation of the model is based on an internal variable approach with the assumption of non-constant material functions.

Another more recent model frequently used for seismic applications was introduced by Fugazza (2003), who developed a modified version of a uniaxial constitutive model proposed by Auricchio and Sacco (1997). The model is simple enough to implement into simulations and capable of reproducing partial and complete transformation patterns. However, drawbacks of the model are rate and temperature independence and assumption of same elastic properties between austenite and martensite.

Auricchio et al. (2007) studied a viscous model that is based on the inclusion of a direct viscous term in the evolutionary equation for the martensite fraction in order to account for strain rate effects on the response of superelastic SMAs. In another study, they proposed a thermo-mechanical model that considers actual martensite fraction as single variable (Auricchio et al., 2008). This model is also rate-dependent and has the ability to account for elastic properties between austenite and martensite.

Zhu and Zhang (2007) focused on a thermo-mechanical constitutive model to simulate rate-dependent behaviour of superelastic SMAs. The derivation of the model is based on a mechanical law, an energy balance equation, and a transformation kinetics rule. The model was able to predict stress-strain curves of SMAs reasonably well under various loading rates, yet it was temperature- independent.

One of the very few models that considers both rate and temperature-dependent behaviour of SMAs was proposed by Motahari et al. (2007). The formulation of the model is based on Gibbs free energy and the volume fraction of detwinned martensite. The model uses an evolution function that describes the relationship between stress and strain with linear segments. This makes the implementation of the model easier in numerical analyses (Ozbulut et al., 2011).

6.5 Discussion

Industry always focuses on producing a fixed small number of products, produced on a mass scale for economic purpose. The most well know example is Ford Model T, which in the beginning only was produced in one variant, with Ford’s emblematic quote saying: “you can have all the colors you want as long as it is black” (Thuesen & Claeson, 2009).

Nevertheless even the car manufacturing has evolved over the years and by using a product platform, the customer can design his own car. This capability of delivering customer tailored cars increases the customers’ perceived value of the product as unique, while the company still can exploit the economy of scale of mass production (Thuesen & Claeson, 2009).

A key point in this process is the shift from a “demand-driven supply” towards a “supply-driven demand” (Ridder & Vrijhoef, 2006). In the construction field, usually suppliers react to the demand of the clients, while industry suggests that the suppliers should take the initiative, providing to the client a set of options to select among the available products (Thuesen & Claeson, 2009).

Allying flexibility with progressive and industrialized technologies, framing is the most appropriate form of construction to deal with the differing needs of the occupants, allowing a selection of possible finishing and plan options. This gives great advantages during the construction process, because it allows greater customization and individualization of the space, but also at a later stage, giving the possibility to change the layout of a unit according to changes within a family, without large modification costs.

A recurring question is also the selection between low-tech and high-tech solutions, and in particular, the definition of which one is more suited to achieve a sustainable development of architecture and urban design. A certain tendency towards a low–tech approach can be discerned amongst many architects in practice and in research, but it seems more grounded on an emotional than intellectual level. This development is somehow fascinating and, at the same time, somewhat disconcerting for a society which depends so much on technology in everyday life (Cody, 2014).

7. THE ADAPTIVE EXOSKELETON – DEFINITION

7.1 Introduction

Although the word “bionics” was coined by Jack Ellwood Steele in 1960, it is not a new concept that nature can inspire technical solutions for architectural and engineering fields (Bar-Cohen, 2006; Bhushan, 2009; Hu et al., 2013; Vincent, 2006). In ancient Greek and Roman cultures, Corinthian order is decorated with acanthus leaves. During the Art Nouveau, plant-derived forms were used in the windows, arches, even decorating entire building facades. Velcro as well is a major achievement of early bionics and a novel adhesive technology inspired by the burs of a fruit stuck in the fur of a dog.

In the first decade of the 21st century, the extent of bionic research has developed into an unprecedented level (Hu et al., 2013) and the expansion of publication on the theme now reached the level of 3000 papers per year (Lepora et al., 2013). This fast trend indicates the potential for having a significant impact on the development of novel technologies.

The main change occurred in the last century is due to the fact that, if in the past the bio-inspired design mostly concentrated on copying geometrical features from nature, recently both architects and engineers concentrated on using the mechanistic and material level inspiration. Aside from mechanical-level inspiration, engineers are putting their effort in discovering, and eventually reproducing, intelligent features of natural creatures, such as the ability to self-adapt, self-control, or the energy efficiency. A broader discussion around bio-inspired design can be found in some reviews (Aldersey-Williams, 2004; John et al., 2005; Knippers & Speck, 2012).

There are different possible approaches to biomimetic design and any different approach can lead to different solutions with different rate of optimization and sustainability. It is also demonstrated (Reap et al., 2005) that biomimetic approach will not necessarily result in a more sustainable and effective solution.

In this research, bio-mimicry is seen as a source of innovation in the definition of a new design concept (Baumeister, 2007). In particular, given our set of problems and requirements, the question was to match those to living organisms needing to solve similar issues: it is the design looking into the biology to find a corresponding model.

The research project has the final objective to find a conceptual model of seismic and adaptive exoskeleton for the requalification of the social housing buildings lacking of aesthetic, morphological and architectural values to translate it in a physical model (Scuderi, 2015).

Thinking about the retrofit of the social housing stock, the principles of the bio-mimicry (Pawlyn, 2011) suggests the possibility to intervene with the application of a new external structural envelope, called “adaptive exoskeleton”.

In the animal world, the exoskeleton is an external, light and resistant armour connected with other apparatuses. Its role is to protect the internal areas of a body from external inputs, such as excessive sunlight and temperature or impacts and attacks. In this way, the exoskeleton performs a complex set of roles, from the structural to the thermal, from the aesthetical to the functional (University of Bath, 2008).

The building exoskeleton, as an enclosing capsule, can protect and support the existing building, which can be preserved and enhanced in terms of performance, safe and safety, seismic behaviour and aesthetic quality.

The exoskeleton defines also external appearance and thermal regulation adapting to environmental conditions, so it has all the architectural, functional and structural properties that can describe a structural envelope.
The bio-mimicry approach underlined also a new possible issue to take into account: the adaptability. Such as the exoskeleton of an insect can adjust and modify in the time in order to respond to the growth, it is possible to imagine a new model for social housing, changing over time to respond to the new requirements of the user and of the market.
In this way, the process of recovering of estates is effective not only in relation to the improvement in structural and functional behaviour, but also because it is able to define new living conditions (De Rossi, 2004).
All architecture is adaptable on some level, as buildings can always be adapted manually and Brand (1995) provides an insight into the different levels of adaptation to be expected and how these apply over different time scales in this thesis. “Adaptive” is concerned with buildings that are specifically designed to adapt, whether this is automatically or through human intervention.
In this chapter the proposed retrofit strategy will be presented through the results of the architectural experimentation conduced at the University of Brescia (Italy). The author, explaining the choices and the related benefits, will then define the structural scheme of the “adaptive exoskeleton”. The last paragraph focuses on the selection of the appropriate design for the seismic devices allocated at the passive dissipation of the horizontal loads.

7.2 Architectural experimentation

The research unit "Architecture and Construction" of Department of Civil, Architectural and Environmental Engineering and Mathematics (DICATAM) at the University of the Study of Brescia is developing a broad experimentation in the field of “adaptive exoskeletons”.
The sub-unit “Architecture”, coordinated by the Professor Marina Montuori, is composed by Arch. PhD. B. Angi, Arch. PhD. M. Botti, Arch. PhD. G. Celeghini, Arch. PhD. F. Orsini, Eng. A. Peroni, Eng. G. Scuderi (PhD candidate and the author of this thesis).
The group is experimenting an operative practice of “adaptive maintenance”, on the strand of Robert Kroneburg’s definition (2007), based on the use of building systems that are reversible, low tech, with low impact and able to convey a renewed relation between typology and technology.
It is an “integrate” system of construction works capable to update, technologically and typologically, the architectural objects, thanks to standardised and interchangeable components and building systems. This with a dual objective: “preventive”, to avoid the degradation of the constructions, and “corrective” to reintegrate a qualitatively improved performance standard.
This practice have been applied in two fields of intervention: the sustainable and integrated requalification of the residential habitat and the recovery of industrial and/or dismissed areas.

Figure 7.1
© V. Damioli, M. Dò, Esercizi di rigenerazione urbana nel quartiere San Bartolomeo a Brescia, Master's Thesis in Architectural engineering, University of Brescia – Department DICATAM, (2013).

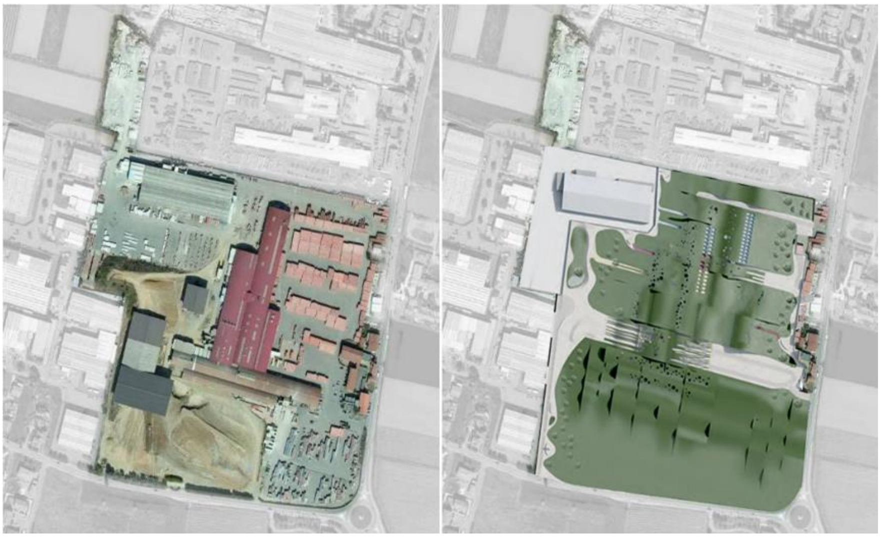


Figure 7.2
© G. Tarantola, C. Scaroni, Recupero e riqualificazione dell'ex Area Industriale Vela a Corte Franca, course and laboratory of Architectural and urban design 2 (University of Brescia) 2014.

The technological device defined "adaptive exoskeleton", has been developed as a structural system morphologically comparable to a stiffening framework, external to the existing building and collaborating with it to optimize the structural response and the energetic performances, and to improve the quality of the internal spaces. This is a technological superstructure that includes new services and seismic devices.
The "adaptive exoskeleton" exploits dry and reversible technological solutions, in a perspective of resource saving and recycling of construction materials, in order to suggest a concrete alternative to the demolition of obsolescent buildings. New independently designed "objects" (rooms, greenhouses, winter gardens, balconies, etc.) can be inserted inside the structural frame avoiding expensive modification works. In occasion of typological renewal of the entire building, new distributive elements can be then easily added. The realization of new elevations (with new residential units or common structures), if sold or rented, could cover the costs of the retrofit intervention.

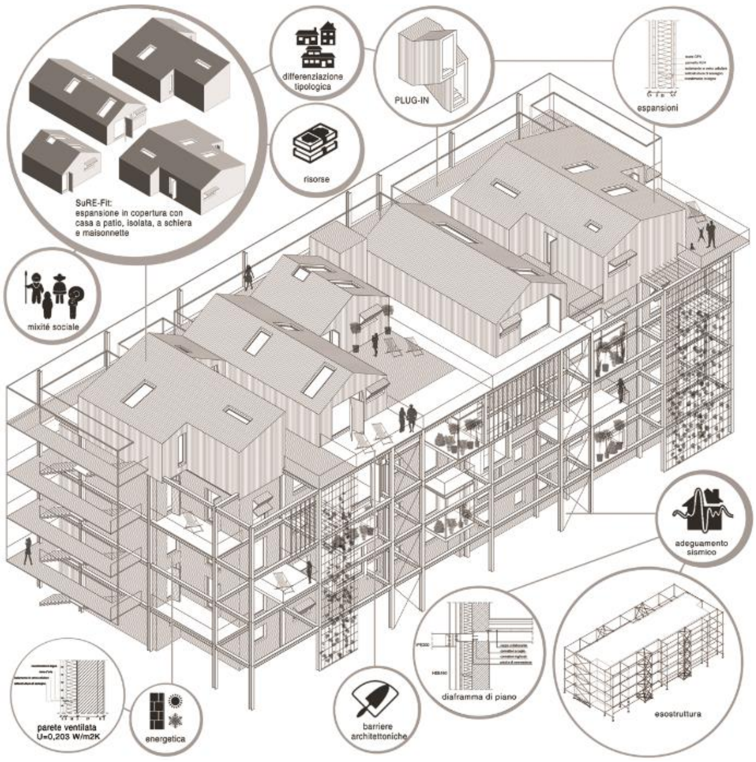


Figure 7.3
© A. Peroni, Strategie tecniche per la manutenzione ragionata del costruito. Il caso del quartiere San Bartolomeo a Brescia: un progetto integrato di riconfigurazione architettonica e strutturale, Master's Thesis in Architectural engineering, University of Brescia – Department DICATAM, (2013).

This practice can be used in different geographical, climate and urban contexts because, beside the steel frame, it grants absolute freedoms in the selection of the materials, performances and aesthetical features.
The final objective of the "adaptive exoskeleton" is to prolong the life cycle of the artefact thanks to the progressive adaptation, leading to the reduction of the environmental impact of the building itself distributed over a longer time span.
In Europe there are many cases of excellence in the field of architectural regeneration that, besides extending the life of the single building, were able to produce virtuous effects on the surrounding contexts.
To verify the actual urban benefits achieved by this strategy, our work unit experimented the design tools real cases in Italy and abroad, focusing on the integrate recovery of the architectural components (typology and morphology), performances (energy efficiency) and structural elements (seismic resistance) of the buildings, actions that could comprehend also the rethinking of the residential typologies and the redefinition of the open spaces.
The research was extended to the didactic field, exploiting the collaboration with the Authorities connected with the territorial management (Aler and the Municipality of Brescia), developing Master's theses, courses and laboratories focusing on urban regeneration in some of the neighbourhoods of Brescia: San Polo, Casazza, San Bartolomeo, Villaggio Violino, Case Marcolini Facella.
Among the many design method, the "rural-urban" was privileged, a sort of morphological category to build new landscapes introduced by Vicente Guallart (2004) and at the basis of the *Sociopolis* project, created to "explore the possibility to create a 'shared habitat' able to allow a bigger social interaction among its inhabitants, promoting new residential typologies in line with the changed family condition of our time, in a context of high environmental quality".
It is not a *camouflage* crystallizing the building image and preparing it to a future obsolescence, but an "open" system making the object able to react to the changes –social, economic and residential – that it will meet.

The “adaptive exoskeleton” then has the objective of prolonging the life cycle of the buildings (today 50 years for residential heritage) thanks to a progressive adaptation to lead to the reduction of the effects of the building on the environment by distributing those on a larger time span. In this sense, the research can be interpreted like the development of what already experimented in some other countries, in harmony with the objective of the program of the European Union “Horizon 2020”.

7.3 The structural design proposal

The international patent of Balducci (2011) introduced the possibility to use dissipative towers to mitigate the effects of earthquakes in hospitals and schools.

The towers can be strategically located along the perimeter of buildings and they present dampers in their base able to reduce significantly the lateral drifts through passive dissipation of the seismic input.

With respect to the traditional methods, the construction phase of the towers does not interfere with the functionality of the buildings, reducing all the indirect costs; additionally, maintenance, inspection and substitution of the dampers result simpler due to their concentrated localization.

The “adaptive exoskeleton” re-elaborates and merges traditional methods and Balducci’s one (Figure 7.4) providing an integrated solution: the three-dimensional structural envelope, while improving the seismic behaviour of the structure, offers additional space for services and functions, increasing the economic value of the building and improving its energy performances and its architectural characteristics.

The new frame is realized with steel elements, bolted together to allow the greater reversibility and the possibility to modify the structure over the time. The design of the sections of the steel elements is defined in relation to the loads applied (wind, quake, static, etc.).

Seismic dampers are located at the interface between the existing structure and the steel frame, in a place where the dissipation of the lateral load is maximized, as in figure 7.5.

The position of the dampers avoids also uncertainties connected with an altered behaviour of the infill panels. The area is also easily accessible and it provides easy monitoring and substitution of the elements.

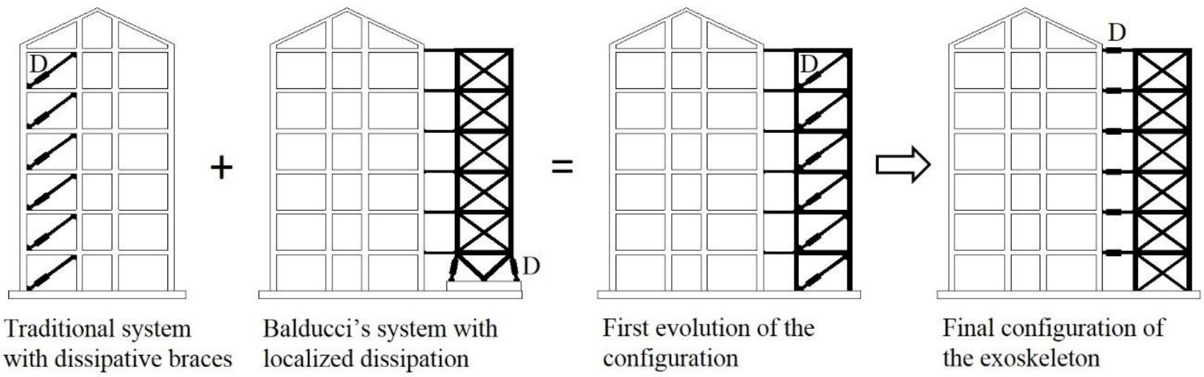


Figure 7.4
Evolution of the structural design for “adaptive exoskeletons”.

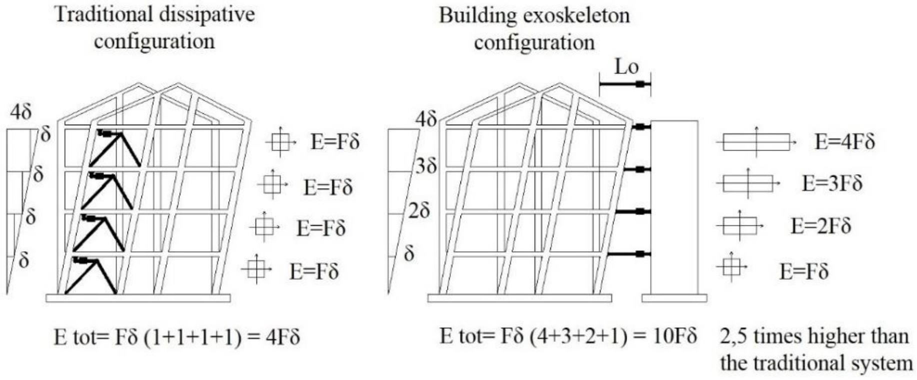


Figure 7.5
Energy dissipated in relation to the different configurations of dissipative devices.

Dampers are passive protection devices very effective in anti-seismic behaviour for new and retrofitted structures.
Even though various types of dampers have been developed over the time, they have numerous limitations related to ageing and durability (e.g., rubber-based dampers), maintenance (e.g., viscous fluid dampers), reliability in the long run (e.g., friction dampers), temperature dependent mechanical performance (e.g., rubber-based dampers, viscoelastic dampers), and geometry restoration (most dampers) after a strong earthquake (Dolce et al., 2000a).
SMA materials have the potential to overcome many of these limitations when applied in such devices (Alam et al., 2007).
Shape memory alloys were selected to implement the dissipative dampers, thanks to their intrinsic properties that have a great potential in retrofitting: recentring and energy dissipation capabilities, excellent corrosion and fatigue resistance, large elastic strain capacity, hysteretic damping.
The first intervention of rehabilitation using shape memory alloys (SMAs) was projected by Indirli et al. (2001) for the bell tower of St. Giorgio in Trignano, Italy, after the significant damages caused by the earthquake of the 1996.
The masonry bell tower of the church was critically damaged and needed to be retrofitted. To increase its flexural resistance, four vertical pre-stressing steel tie bars with four post-tensioned SMA devices connected in series were anchored at the roof and foundation in the internal corners of the tower. SMA devices ensured that the constant force applied to the masonry is maintained at a compressive level of 20 kN (axial capacity of the masonry column). Each SMA device included 60 superelastic SMA wires, 1 mm in diameter and 300 mm in length. The performance of the rehabilitation scheme was positively verified after the tower was shaken by another 4.5 Richter magnitude earthquake and no forms of distress or damage were noticed after this event (Alam et al., 2007).
Croci (2001) and Castellano et al. (2001), after the earthquake of the 1997, studied a method based on SMAs to reduce the seismic input on the tympanum of St. Francesco church in Assisi, Italy, connecting the element to the roof through superelastic multi-plateaus SMADs.
The devices constitute an axial constraint with variable stiffness in relation to the imposed displacement, following a force-displacement relationship characterized by one or more plateaux (force almost constant for increased displacements). In this way, the devices are able to limit the loads transferred to the rear structure. The efficiency of this technique in comparison with traditional technologies have been demonstrated through numerical analysis and experimental tests.
In this application, the main challenge of the restoration was to obtain an adequate safety level while maintaining the original concept of the structure.

After these first experimentations, the unique properties of SMAs have inspired the creation of damping devices, as the one projected by Krumme et al. (1995) and shown in figure 7.6, in which SMA wires work always in tension, while the input loads can be of tension or of compression. Krumme et al. (1995) examined the performance of a sliding SMA device in which resistance to sliding was achieved by opposite pairs of SMA tension elements. Experimental results reported temperature insensitivity, frequency independence and excellent cyclic behaviour.

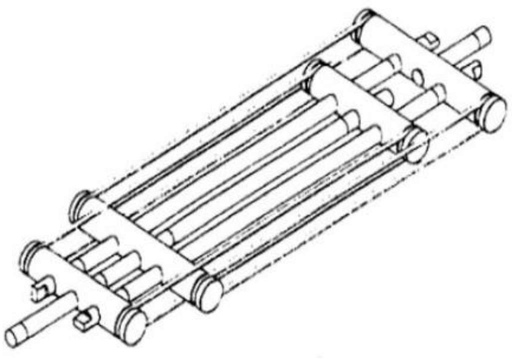


Figure 7.6
The dissipative device designed by Krumme et al. (1995).

Clark et al. (1995) performed an extensive testing program on a wire-based SMA devices to evaluate the effects of temperature and loading frequency on their cyclic behaviour. The devices used a basic configuration of multiple loops of superelastic wires wrapped around cylindrical supports. Two pairs of devices were tested and each of the four devices had identical hardware but different wire configuration. The proposed dampers exhibited stable hysteresis with minor variations due to frequency of loading and device configuration (single layer versus multiple layers of wires). Moreover, the research highlighted that the temperature effects were substantial in the single-sided device.
Dolce et al. (2000a) studied in great detail the possibility of using special braces for framed structures using SMAs. Due to the extreme versatility of such materials, they could obtain a wide range of cyclic behaviour (from supplemental and fully recentring to highly dissipating) by simply varying the number and/or the characteristics of the SMA components. In particular, they proposed three categories of devices: supplemental re-centring devices, not re-centring devices and re-centring devices.
Dolce and Marnetto (2000), figure 7.7, created a more complex variation of the precedent device, consisting of the coupling behaviour of NiTi wires, with re-centring capabilities, and of steel elements, with energy dissipation properties.

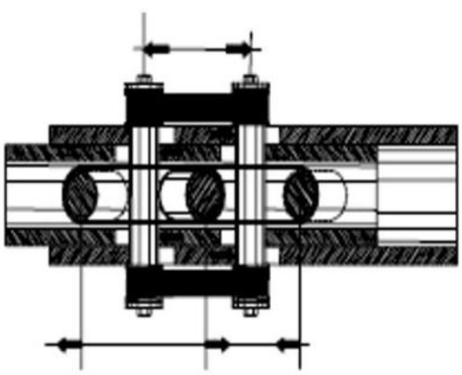


Figure 7.7
The dissipative device designed by Dolce and Marnetto (2000).

Dolce et al. (Dolce et al., 2000b; Dolce et al., 2005) proposed Nitinol-based devices with full re-centring and good energy dissipation capabilities. The kernel component of such a device consists of two groups of Nitinol wire loops, i.e. re-centring group of superelastic Nitinol wires and an energy-dissipating group of Nitinol wires, which are mounted on two concentric tubes. Their full-scale brace, being designed for a maximum force of 200kN and a 20mm displacement amplitude, can be used as a bracing element in framed structures (Ren et al., 2008).

The device employs pre-tensioned superelastic wires placed on the device so that they are only strained in tension for re-centering capability and supplemental martensitic bars or austenitic wires used for additional energy dissipation. By changing the number and characteristics of the two groups of SMA elements, the desired performance of the device can be accomplished. Experimental tests of the full-scale prototype of braces and isolation devices were carried out to demonstrate the capability of the device.

Bruno and Valente (2002) presented a comparative analysis of different passive seismic protection strategies, aimed at quantifying the improvement achievable with the use of innovative devices based on SMAs in place of traditional steel or rubber devices.

The researchers found that SMA-based devices were more effective than rubber isolators in reducing seismic vibrations. On the other hand, the same conclusions could not be drawn for SMA braces if compared to steel braces because of the similar structural performance. However, SMA braces showed recentring capabilities not possessed by steel braces as well as the reduced functional and maintenance requirements.

The comparison was carried out on ‘new’ buildings, complying with the EC8 seismic provisions, or ‘existing’ buildings, not designed to sustain horizontal earthquake actions. The seismic response of both ‘new’ and ‘existing’ buildings was analysed with and without passive protection systems.

Dolce et al. (2005) performed shake table tests on reduced-scale RC frames endowed with either steel or SMA braces. The experimental outcomes showed that the new bracing system based on SMAs may provide performances at least comparable to those provided by currently used devices, also in the absence of design criteria and methods specifically addressed to the new technology. With respect to steel braces, the innovative bracing configuration presented excellent fatigue resistance and recentring ability.

Although these studies provided a critical overview of the topic, there have been significant research beside them (Ozbulut, 2011).

7.4 The seismic devices: design and characterization

Modelling the behaviour of shape memory alloys is a complex topic of permanent interest. The complexity of the martensitic transformation of the SMA requires a formulation at various levels, and the importance of each level depends on the requirements which are to be satisfied by the material in the working situations (Torra et al., 2007).

In general, three fundamental steps are connected with the design of the devices: (1) the selection of the most suitable alloy, (2) the selection of the shape, and (3) the selection of the behaviour (Dolce et al., 2000b).

Selection of the alloy

Binary Ni-Ti as well as ternary Ni-Ti-X alloys are certainly the most researched types of SMAs and have become the most important material for commercial applications.

This binary system is based on an almost equal-atomic compound of nickel and titanium. For commercial exploitation, and in order to improve its properties, a third metal is usually added to the binary system. Increasing the nickel composition above 50 atomic percentage decreases the transformation temperature.

Hence, the range of phase transformation temperatures can be adjusted by altering the composition of the alloys (Ozbulut et al., 2011; Auricchio et al., 2006).
The addition of a third metal to NiTi to compose a ternary can result in desirable properties for specific applications. For example, NiTiCu has lower hysteresis associated with phase transformations, which makes it a better choice for actuators (Bassani & Besseghini, 2001).
On the other hand, the addition of Niobium (Nb) results in wider thermal hysteresis (Simpson et al., 1986), showing minimal response to large temperature changes and NiTiNb is preferred for coupling applications.
It is also possible to obtain SMAs for applications operating at high temperatures by adding a third element such as palladium, platinum, hafnium, and gold to the NiTi. In this way, transformation temperatures can be shifted anywhere in the range 100-800°C (Kumar & Lagoudas, 2007).
Due to its excellent deformation behaviour and a very good fatigue resistance, Ni-Ti was successfully used in many investigations on damping.
Since most of the seismic applications of SMAs rely on the superelastic effect of the SMAs, the mechanical properties of the superelastic SMAs are discussed in this section. The sensitivity of these properties to various factors such as temperature, strain rate, cyclic loading, and thermo mechanical treatment is also examined.

1) Cyclic loading

Some researchers have studied the effect of cyclic loading on NiTi wires with diameter 1.2 mm (Dolce and Cardone, 2001; DesRoches et al., 2004). They found that there is a considerable decrease in forward phase transformation stress level with the number of loading cycles. Specifically, the greatest variation was noted between the first and second cycles.
Therefore, the dissipated energy reduces for increasing number of loading cycles. Another effect of the cyclic loading is the increase in residual deformation even if, the material tends to have a stabilized behaviour after a given number of cycles.
The cyclic behaviour of large diameter NiTi bars has been investigated by several researchers. DesRoches et al. (2004) tested 1.8, 7.1, 12.7, and 25.4 mm specimens to evaluate the effect of bar size on the superelastic behaviour of NiTi SMAs. They found that both wires and bars exhibit almost ideal superelastic properties. The re-centring capability of the superelastic SMAs was found to be similar for different sizes, but lower strength and damping capacity were observed for bars.
Ensuring a guaranteed working lifetime for SMA dampers requires that the working cycles remain always inside the pseudoelastic window or pseudoelastic working space in stress–strain-temperature coordinates.
The first check concerns the self-heating induced by the internal dissipation at the working frequencies and the effects produced by the external changes in surrounding temperature are decisive as they modify the stress–strain response of the material.
It is also determinant for systems working during several years the careful analysis of diffusion effects guaranteeing that non-relevant parasitic effects in static or in dynamic situations cannot move the hysteretic behaviour out of the range.
The practical application of SMA dampers requires that the length of the dampers does not increase progressively due to cycling via either plastic deformation or some mixed effect of creep and martensite stabilization. An increase of length induces bending without damping effect for lower amplitudes (Isalgue et al., 2006).

2) Strain rate effect

Although martensitic phase transformations are time independent phenomena, experimental tests conducted at different loading rates have revealed that the strain rate has a significant influence on the mechanical behaviour of NiTi.
The reason for the rate-dependent behaviour is the complex coupling between stress, temperature, and rate of heat generation during stress-induced phase transformations. During the forward phase transformations, the material releases energy in the form of heat, while it absorbs energy in the case of unloading.

The material may not have enough time to transfer latent heat to the environment during loading with high strain rates. As a result, the temperature of the material changes and this, in turn, alters the shape of the hysteresis loops and the transformation stresses.
In the past studies, different conclusions were made about the effect of loading rate on the transformation stresses and the energy dissipated. Ren et al. (2008) reported an increase in the reverse transformation stress without a significant change in the forward transformation stress and a decrease in the energy dissipated with the increased strain rates. Dolce and Cardone (2001) and DesRoches et al. (2004) noticed an increase in both forward and reverse transformation stresses with increasing strain rates. Since smaller increases were observed in the forward transformation stress, a reduction in the energy dissipated was reported.
The inconsistency in the findings of the previous studies regarding the strain rate effects on the superelastic behaviour of NiTi SMAs can be attributed to factors such as using materials with different compositions, testing at various ranges of strain rates, and experimental conditions.

3) Temperature effects

Since phase transformations of SMAs are not only dependent on mechanical loading, change in the temperature significantly affects the superelastic behaviour of NiTi alloys. It is not only the testing temperature that influence the behaviour but also its position with respect to transformation temperatures.
A number of experimental studies have been conducted to investigate the effects of temperature on superelastic SMAs (Dolce & Cardone, 2001). It was reported that the critical stress that initiates the phase transformation noticeably changes with temperature. In particular, an increase in temperature corresponds to a linear increase in transformation stress. It was found that the equivalent viscous damping linearly decreases with an increase in the temperature.
In addition, it was observed that the initial stiffness and residual strain were not affected by the variation of the temperature in the superelastic range.
The sensitivity to temperature, though not negligible, appears to be compatible with the typical applications in the field of civil engineering, also considering that similar and even stronger dependence on temperature can be found in other devices for passive control, especially those based on polymers (rubber and other visco-elastic materials). In any case, it's important to check the compatibility of the mechanical variability due to temperature of the device as a component of a structural system. At worst, in particular situations, the devices could be protected from temperature changes.
It must be observed that if an earthquake occurs when temperature is very low, the supplemental re-centring force could not be fully available, since it reduces when temperature decreases. Thus a residual displacement could occur at the end of the earthquake. As soon as temperature increases, however, the structure would be automatically re-centred, as tests carried out at variable temperature, under constant force, demonstrated (Dolce et al., 2000a).
Extreme temperature conditions can completely eliminate the shape memory or superelastic effects within a specimen.

4) Corrosion and aging

The corrosion resistance of the NiTi SMAs is generally higher than that of other SMAs and austenitic stainless steel. They have an overall good corrosion behaviour due to the presence of a passive film acting as a protective layer.
NiTi-based SMAs are also known to be less prone to degradation than Cu-based SMAs. However, the aging procedure can affect the transformation temperatures and thermal hysteresis as well as the mechanical and functional properties of the alloy.

Selection of the shape

Taking into account the limited workability of the material, kernel components for devices can only be drawn from wires or bars.

They differ from each other for the diameter (up to 2 mm for commercial wires, from 6 to 8 mm for commercial solid bars, up to 50 mm for special production bars), as well as for the stress distribution they will be subjected to in practical applications (tension for wires, bending and/or torsion and/or shear for bars).
Due to the hardness of the material, machining large bars is extremely difficult, and requires special tools to be performed adequately. In addition, welding of shape memory alloys is often difficult because, when Nitinol is welded to another material, it creates a brittle connection around the welding zone. Heat treatment is then required to increase the ductility of the connection, though this generally eliminates the superelastic effect of the alloy (DesRoches et al., 2004).
Wires are used only in the austenitic phase, thanks to their superelasticity that makes them undergo loading-unloading cycles without any residual strains. On the other hand, bars can be employed either in martensite or in austenite phase, according to the desired device behaviour (Dolce et al., 2000b).
A SMA damper may be simply a wire or rod of material that, due to its hysteresis cycles, is able to convert mechanical energy into heat. In principle, we may use a single SMA rod with an appropriate thickness to endure the stress in the structure, but, there are several reasons that suggest the use of a set of thinner SMA wires instead.
Nevertheless, industrial production and seismic engineering applications are markedly oriented to wires, due both to economic convenience considerations and to the uniform stress distribution they are subjected to in operating conditions. In fact, the special arrangement of wires in re-centring devices is such that they are always subjected to tensile strains, whatever the sign of the mutual movements of the component parts be. Therefore, resorting to wires rather than to different material shapes such as bars or plates, characterized by more complex, non-uniform stress distributions, guarantees considerable stability in the mechanical properties of the device (Duerig et al., 1999; Bruno & Valente, 2002; DesRoches et al., 2004).
Obviously, this configuration only allows the dampers to work in traction while no compression work is achievable.
To overcome this limitation, the dampers always work in pairs on a counteracted geometry.
The design and optimization of the dampers consist of determining the best length and number of wires that compose the damper in a given structure.
To ensure an appropriate response of the dampers, we consider only strains up to 3.5–4%. This limitation has two aims: to reduce the accumulated creep and to provide a safety margin
From the free oscillation amplitude, we determine the length of the SMA wires in order to not overcome the maximum expected strain in the SMA with stresses under plastic deformation. We calculate the number of wires required to produce a total stress around 10–30% of the stresses induced in the structure by the event, expecting a significant action of the dampers with this choice. Usually, starting from these data, a trial and error iterative process is required to optimize the dampers.
One of the limitations of our dampers is the necessity of minimum oscillation amplitudes in order to dissipate energy. Therefore, dampers working in the elastic part do not damp small oscillations. To eliminate this limitation and increase the mechanical efficiency of the dampers, wires with a certain prestress can be used (Torra et al., 2007).

Selection of the behaviour
Full re-centring and good energy dissipation were chosen as the main targets of the conceptual design of SMA-based devices.
Functional simplicity, no maintenance need, limited encumbrance and compatible costs were selected as additional objectives in their implementation.
It must be emphasized that the two main targets (re-centring and energy dissipation capability) are somewhat conflicting. As a matter of fact, the maximum energy dissipation for a given maximum force is obtained in a rigid-plastic behaviour, while re-centring necessarily requires the force-displacement cycle to pass through the

axis origin. Therefore, the loop shape has to be optimised to get maximum energy dissipation compatibly with the second condition.
The experimental performances of SMA elements suggested that the optimal manner to provide self-centring capability requires (pre-tensioned) austenitic superelastic wires to be arranged in the device in such a way as to be always stressed in tension. It is also clear, however, that they must be supplemented with an additional dissipating mechanism, in order to provide the devices with the necessary energy dissipation capability. At this end, pre-tensioned austenitic superelastic wires, arranged like in a double counteracting system of springs, can be utilized.
A straightforward and easy implementation of a device with the above-described behaviour can be realized by using two concentric pipes that move mutually when inserted in a structure subjected to seismic actions, their ends being connected to relatively moving parts of the structural system.
To realize the SMA wire re-centring group, two studs can be inserted transversely in the two tubes, into oval-shaped holes. An adequate number of superelastic wires are wound around the studs, which also have a mechanism to apply and calibrate pretension. The special arrangement of studs and holes is such that, for any positive or negative mutual movements of the tubes, the wires are always subject to elongation, thus increasing the initial tensile strain (Dolce et al., 2000b).
To assure an optimal behaviour, the imposed pre-strain must be calibrated carefully with respect to the foreseen maximum displacement, in order to avoid the buckling of a wire loop, on the one hand, and the completion of the phase transformation, on the other.
A specific concern is relevant to existing structures, for which SMA-based systems appear to be optimal candidates. As far as bracing systems are concerned, until now all the applications and the research studies on this technique were focused on the energy dissipation capability. The availability of SMA-based devices, which are able to provide supplemental forces to recover the unreformed shape of the structure at the end of the action, suggest new design concepts, especially useful for seismic retrofitting.

7.5 Discussion

The suppression of vibration in civil structures to external dynamic loading can be pursued by using active control, semi-active control, and passive control. In the active control mode, an external power source controls actuators to apply forces to the object structures. For a passive control system, no external power source is required and the impact forces are developed in response to the motion of the structures. The semi-active control devices use considerably less energy to adjust the structural properties than the active control devices.
The passive structural control using SMAs takes advantage of the damping property to reduce the response and the consequent plastic deformation of the structures subjected to severe loadings. SMAs can be effectively used for this purpose via two mechanisms: ground isolation system and energy dissipation system. In a ground isolation system, SMA can be isolators installed between a super-structure and the ground to assemble an uncoupled system, filtering the seismic energy transferred from the ground motion to the superstructure so that the damage is attenuated (Song et al., 2006).
On the other hand, via the energy dissipation mechanism, martensite or austenite SMA elements integrated into structures absorb vibration energy based on the hysteretic stress–strain relationship.
Although the two mechanisms are based on the damping capacity of SMAs, they are different in arrangement and function. An SMA isolator provides variable stiffness to the structure according to the excitation levels, in addition to energy dissipation and restoration after unloading. On the other hand, SMA energy dissipation element mainly aims to mitigate the dynamic response of structures by dissipating energy.

In general, for SMA devices for passive vibration control, martensite SMAs have a larger damping capacity; however, it requires external heat to cause a phase transformation to restore its original shape. On the other hand, superelastic austenitic SMAs have a smaller damping capacity, but they have a strong re-centring force to restore the structure's initial position with little residual strain.

The SMAs considered most widely for structural applications do not involve heating and active control but, rather, exhibit this superelastic effect. Besides possessing unique re-centring ability and considerable energy dissipating capacity, superelastic SMAs have also favourable properties such as the ability to undergo large deformations, good fatigue resistance, and excellent corrosion resistance (Ozbulut et al., 2011).

Although actual applications of SMAs in civil engineering are rare, there have been extensive research efforts on the use of SMAs in civil structures for the seismic response control. The analytical and experimental studies have proven that the structures with SMA devices improve the seismic response, but further research is needed to evolve design guidelines for SMA based seismic protection systems. The development of code and standards will foster the applications of SMAs in civil structures (Ozbulut et al., 2011).

Another impediment to actual implementation has been quoted as the high cost of SMA material. The cost of the alloy will be largely lowered once a large amount of material is consumed with the actual implementation of SMAs in civil structures. Furthermore, to reduce the cost associated with manufacturing processes of SMA material, considerable research efforts have been made in recent years.

Alternative production techniques such as powder metallurgy for manufacturing SMAs can avoid or minimize the problems related to the conventional casting methods, which are the expensive thermo mechanical treatments, machining, and associated material losses.

8. THE ADAPTIVE EXOSKELETON – VERIFICATION

8.1 Introduction

Most of the existing seismic design codes are based on the empirical knowledge accumulated through systematic earthquake damage data collection and their analysis. Required levels of protection and seismic design forces, gradually increased only after each series of catastrophic earthquakes (Petrovski, 2004).
A conventional structural system is designed to achieve a set of intended functions under pre-selected loads and forces and it cannot successfully develop ability against unexpected events, unless a large safety factor is provided to take into account various uncertainties, such as load amplitudes and structural response. Furthermore, since seismic design requirements have been improved after each lesson learned through past earthquakes, the safety levels of old buildings are always inferior to new buildings as evidenced in many past disasters. Strengthening those old buildings becomes necessary to protect societal welfare (Otani et al., 2000).
In general, linear procedures are applicable when the structure is expected to remain nearly elastic during ground motion or when the design results in nearly uniform distribution of nonlinear response throughout the structure. As the performance objective of the structure implies greater inelastic demands, the uncertainty with linear procedures increases to a point that requires a high level of conservatism in demand assumptions and acceptability criteria to avoid unintended performances. Procedures incorporating inelastic analysis can reduce the uncertainty and conservatism.
Modern seismic design codes allow engineers to use either linear or nonlinear analyses to compute design forces and displacements, anyway performance based design methods with nonlinear analysis provide a more realistic behaviour of structures.
Linear and nonlinear methods differ in respect to accuracy, simplicity, transparency and clarity of theoretical background. Non-linear static procedures were developed with the aim of overcoming the insufficiency and limitations of linear methods, whilst at the same time maintaining the relatively simple application. All procedure incorporate performance-based concepts paying more attention to damage control. The main source of damage to structural systems and in particular non-structural elements are deformations and interstory drifts imposed by earthquake ground motions. Therefore, to control damage, it is necessary to control deformation and particularly to control interstory drift (Petrovski, 2004).
Enabled by advancements in computing technologies and available test data, nonlinear analyses provide the means for calculating structural response beyond the elastic range, including strength and stiffness deterioration associated with inelastic material behaviour and large displacements. As such, nonlinear analysis can play an important role in the design of new and existing buildings.
Nonlinear analyses involve significantly more effort and should be approached with specific objectives in mind. Typical instances where nonlinear analysis is applied in structural earthquake engineering practice are to: (1) assess and design seismic retrofit solutions for existing buildings; (2) design new buildings that employ structural systems that do not conform to current building codes; (3) assess the performance of buildings for specific requirements (Causevic & Mitrovic, 2011).
In recent years, the state of the art of seismic analysis has increased along with the development of technology. The developments in computer hardware and software have made analysis techniques that were formerly too

expensive within the reach of most project budgets. However, this increase in accuracy comes at a steep price. The analysis technique requires a deep understanding of the structure being analysed. The final solution must also be carefully interpreted and the importance of these issues increases with the complexity and size of the model (Finley & Cribbs, 2004).
Nonlinear static procedures use equivalent SDOF structural models and represent seismic ground motion with response spectra. Story drifts and component actions are related to the global demand parameter by the pushover or capacity curves that are the basis of the non-linear static procedures.
A pattern of horizontal forces is applied to a model that includes non-linear properties until a “target displacement” is reached, and the total force is plotted against a reference displacement to define a capacity curve. This can then be combined with a demand curve reducing the problem to a single degree of freedom (SDOF) system.
This analysis, known as pushover, is more indicated for assessing the seismic vulnerability of existing structures. A control point is defined for the target displacement, usually at the top (roof level) of the structure.
In contrast to the nonlinear static procedure, the nonlinear dynamic procedure, when properly implemented, provides a more accurate calculation of the structural response to strong ground shaking. Since the nonlinear dynamic analysis model incorporates inelastic member behaviour under cyclic earthquake ground motions, the nonlinear dynamic procedure explicitly simulates hysteretic energy dissipation in the nonlinear range.
The dynamic response is calculated for input earthquake ground motions, resulting in response history data on the pertinent demand parameters. Due to the inherent variability in earthquake ground motions, dynamic analyses for multiple ground motions are necessary to calculate statistically robust values of the demand parameters for a given ground motion intensity or earthquake scenario. As nonlinear dynamic analysis involves fewer assumptions than the nonlinear static procedure, it is subject to fewer limitations than nonlinear static procedure. However, the accuracy of the results depends on the details of the analysis model and how faithfully it captures the significant behavioural effects (Deierlein et al., 2010).
The most precise description of the problem is by far the non-linear dynamic seismic analysis, made by applying time history record which, in the long term, represents the correct development path. Yet, due to its complexity and high standards it goes beyond the frames of practical application and it is appropriate just for the research and analysis of structures of special significance. This approach is the most rigorous, and is required by some building codes for buildings of unusual configuration or of special importance (Causevic & Mitrovic, 2011).
If the first widespread practical applications of nonlinear analysis in earthquake engineering were to assess and retrofit existing buildings, more recently, the role of nonlinear dynamic analysis for design is being expanded to quantify building performance more completely.
In this chapter nonlinear static and dynamic analyses will be applied to two structural typologies typically used in social housing stock. Theoretical buildings will be used for the evaluation and they will be considered before and after the application of the “adaptive exoskeleton” with SMADs. Finally, the strategy will be verified on a real case study.

8.2 Concrete frame with masonry infill

Infill walls and panels are commonly encountered in existing buildings around the world and in regions of low to moderate seismicity.
The system is conventionally modelled as a frame structure with beams and columns braced with one or two diagonal struts representing the masonry infill. In most cases, the infill panel failure will initiate in sliding along the horizontal joints, since the capacity is limited by the shear strength of the mortar. Alternatively, if the panel

is strong in shear, the diagonal strut will crush near the frame joints and lose strength. This mode of failure has limited deformation capacity because the crushing will be abrupt. The large panel forces generated in this mode will be distributed along the beam and column members, and they may result in either column or beam shear failures.
Depending on their height-to-thickness slenderness, unreinforced infill walls can also fail out-of-plane, sometimes in combination with one of the other modes. For either the shear sliding or compression crushing mode, it is reasonable to analyse frames with infill using two diagonal compression struts for reversed cyclic loading analysis.
Designers and engineers usually ignore the structural role of masonry infill in frame structures, considering the mass of the panels but not their strength and stiffness.
In fact, sometimes the upper and lateral edges of the panels are detached from the frame enough to avoid any interaction with the structure and therefore they are defined as "isolated" elements.
However, when the infill is built in contact with the frame, it strongly influences the seismic response of the building: with the increase of horizontal loads the panels progressively detach from the frame with horizontal and vertical relative displacements starting to act as equivalent diagonal struts. In this phase is reasonable to model the structure as a frame with diagonal braces with pure compressive behaviour. The prevalent stresses in the infill are normal compressive stresses in correspondence of the corners of the panels, still in contact with the frame, while shear stresses are less influential also because of the X-shaped fractures, typical of shear failure for alternate cyclic seismic loadings. Masonry infill of this type can enhance the lateral stiffness and the resistance to lateral loads, with a noticeable increase in energy dissipation through the formation of X-shaped fractures.
The loads distribution can also be substantially different from case of a bare frame, generating unpredictable solicitations and, subsequently, results.
The presence of infill is not always favourable so not considering its presence can lead to destructive effects such as:

- The formation of soft story mechanisms caused by the irregular vertical pattern of the panels;
- The detachment and consequent fall of the panels;
- The localized brittle failure of structural elements due to irregular openings in the panels;
- The failure of structures with regular plan distribution but with irregular infilling arrangement;
- The formation of plastic hinges in the columns for the high tensile stress caused by the panels.

The literature presents numerous studies about this topic but in this research, Al-Chaar's considerations (2002) are used to define the geometric characteristics of the struts, their behaviour and their location within the frame.

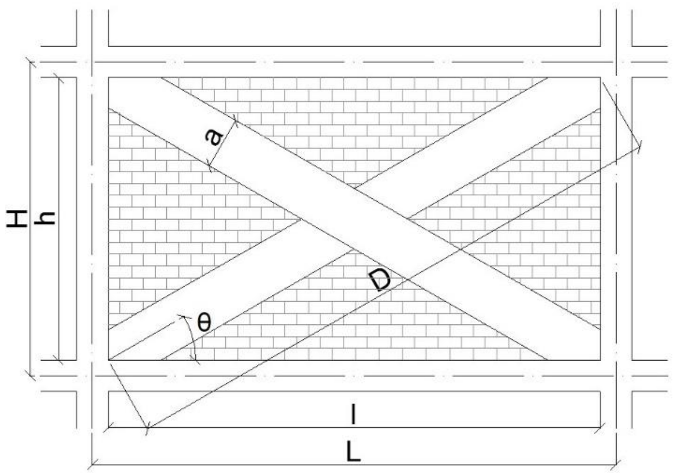


Figure 8.1
Geometrical parameters of the equivalent diagonal strut.

The relative flexural stiffness frame-panel (Smith & Carter, 1969):

$$\lambda_1 H = H \sqrt[4]{\frac{E_m t \sin(2\theta)}{4 E_c I_{col} h}} \qquad (1)$$

E_c concrete Young's module
E_m masonry Young's module
I_{col} moment of inertia of the column
t thickness of the panel

The width *a* of the equivalent strut is function of the previous value with the relation (Mainstone, 1971):

$$a = 0.175 D (\lambda_1 H)^{-0.4} \qquad (2)$$

If the panel presents openings a reduction factor should be applied:

$$R_1 = 0.6 \left(\frac{A_{openings}}{A_{panel}}\right)^2 - 1.6 \left(\frac{A_{openings}}{A_{panel}}\right) + 1 \qquad (3)$$

Anyway if the area of the opening is not minor of 60% of the area of the panel the effect of the infill can be ignored, and $R_1 = 0$.

If the panel is damaged another reduction factor should be considered in relation to table 8.1.

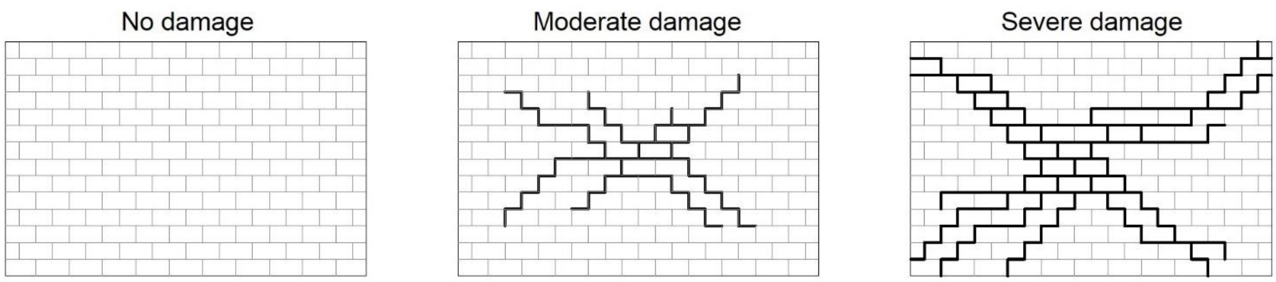


Figure 8.2
Classification of damage for the brick infill.

	R_2		
H/t	No damage	Moderate damage	Severe damage
≤ 2L	1	0.7	0.4
> 2L	1	Intervention required	

Table 8.1
Reduction factor for the level of damage.

The final reduced width of the equivalent strut is:

$$a_{red} = a(R_1)(R_2) \qquad (4)$$

For the purpose of a finite element model it is necessary also to define an equivalent diagonal that is connected to the beam at a distance l_{column} from the frame joint (Figure 8.3) with some particular consideration for partial infill.

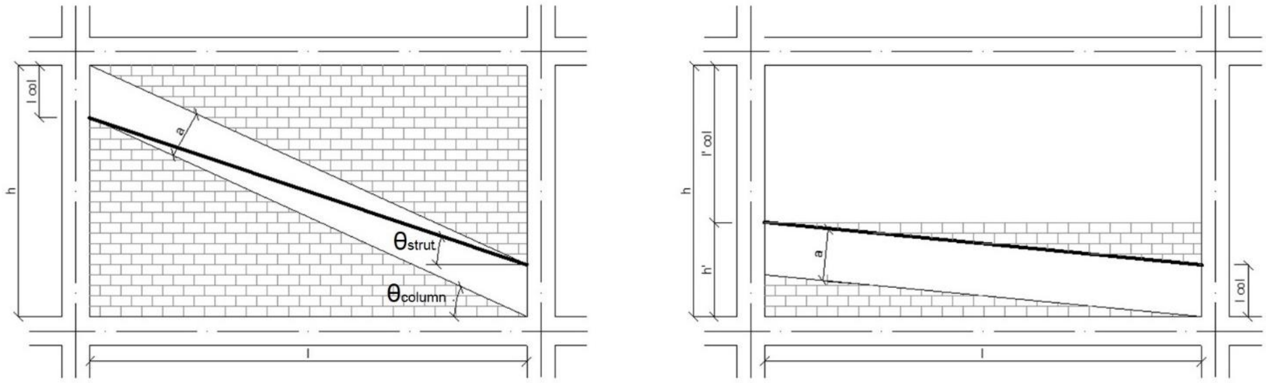


Figure 8.3
Equivalent diagonal strut for full and partial infill.

$$l_{column} = \frac{a}{cos\theta_{column}} \qquad (5)$$

$$tan\theta_{column} = \frac{h - \frac{a}{cos\theta_{column}}}{l} \qquad (6)$$

The strength of the strut is determined calculating the required loads to reach the crushing strength, R_{cr} , and the shear strength, R_{sh}, of the panel and evaluating the component of those loads in the direction of the equivalent diagonal. The minimum value thus obtained represents the load connected to the compressive strength of the equivalent strut, R_{strut} , and it will be used to define the properties of the plastic hinge in the final element software.

$$R_{strut} = min\left\{\frac{R_{cr}, R_{sh}}{cos\theta_{strut}}\right\} \qquad (7)$$

$$tan\theta_{strut} = \frac{h - 2l_{column}}{l} \qquad (8)$$

$$R_{cr} = a_{red}tf'_m \qquad (9)$$

$$R_{sh} = A_n f'_v R_1 R_2 \qquad (10)$$

f'_m masonry compressive strength

f'_v masonry shear strength

A_n net area of the transversal section of the panel.

To determine the position of the plastic hinges it is necessary to define another relation:

$$l_{beam} = \frac{a}{sin\theta_{beam}} \qquad (11)$$

$$tan\theta_{column} = \frac{h}{l - \frac{a}{sin\theta_{beam}}} \qquad (12)$$

Rigid offset are added to avoid the excessive flexibility of the numerical model.

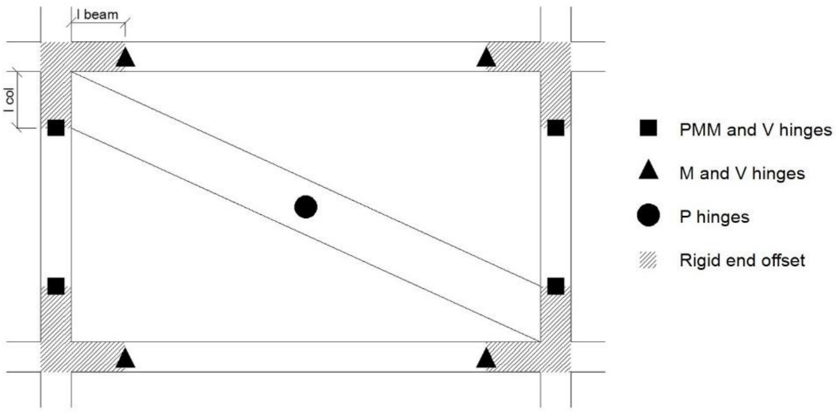


Figure 8.4
Location of plastic hinges and rigid end offsets.

For the relation force-displacement of the equivalent strut Panagiotakos and Fardis's model (1996) is used with a multilinear curve: in compression the curve is composed by four segments, which respectively correspond to the pre-cracking shear behaviour of the panels, to the post-cracking hardening branch after the detachment from the edges, to the instable state after the maximum strength, and to the ultimate state of the panel after the complete damage with a constant residual strength.

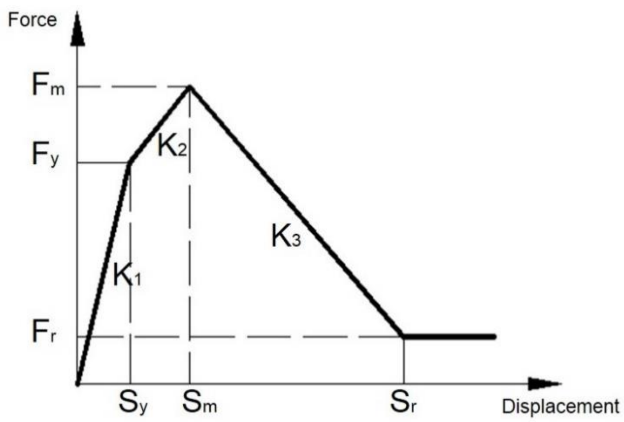


Figure 8.5
Panagiotakos and Fardis's force-displacement relation.

Where the initial shear stiffness of the un-cracked panel is equal to:

$K_1 = \frac{G_m t l}{h}$ (13)

The cracking force is:

$F_y = \tau_{cr} t l$ (14)

The displacement relative to the cracking load is:

$S_y = \frac{F_y}{K_1}$ (15)

The axial stiffness of the equivalent strut is:

$K_2 = \frac{E_m t a}{d}$ (16)

The ultimate force is:

$F_m = 1.3F_y$ (17)

The displacement relative to ultimate force is:

$S_m = S_y + \frac{F_m - F_y}{K_2}$ (18)

The post-ultimate falling branch stiffness is:

$0.005K_1 \leq K_3 \leq 0.1K_1$ (19)

The residual post cracking force is

$F_r = 0.1F_y$ (20)

The ultimate displacement relative to the residual force is:

$S_r = S_m + \frac{F_m - F_r}{K_3}$ (21)

h, l, t, d	height, length, thickness and diagonal of the infill panel
a	width of the strut
τ_{cr}	cracking stress as measured in a diagonal compression test of the masonry

The geometrical values and characteristics are the one already described above with the formulations of Mainstone (1971) and Al-Chaar (2002).

In the finite element software SAP2000 the infill panel are described as "frames" with a pure compressive behaviour and an axial plastic hinge located in the middle section of the diagonal. The force-displacement relation differs from the Panagiotakos and Fardis's one just for the instable falling branch, described as a constant branch in order to improve the numerical stability of the program; this choice does not influence the result of pushover analyses.

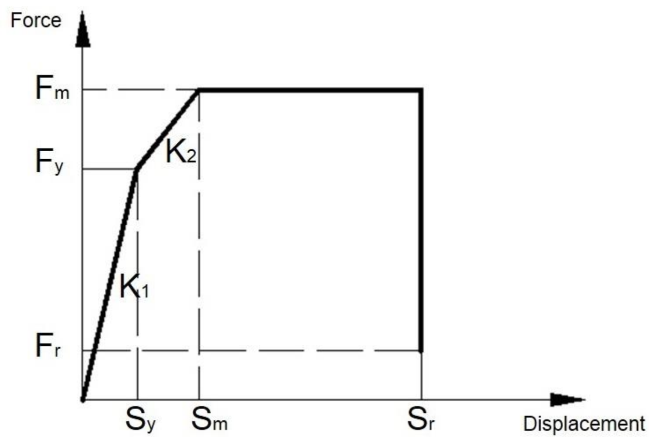


Figure 8.6
Force-displacement relation modelled in SAP2000.

$S_r = 20\, S_m$ (22)

The software SAP2000 assumes for the "hinges properties" a rigid plastic behaviour with the definition by the user of the only the plastic range; the elastic response is indeed evaluated automatically in relation to the

mechanical properties of the material and the geometrical characteristics of the elements. To assign the initial stiffness to the strut is then necessary to increment the section of the strut of the parameter K_1/K_2.
Static and dynamic nonlinear analyses have been performed on a hypothetical concrete frame building with masonry infill, modelled in SAP2000 following the previous explained conditions.
The building has rectangular plan with two bays in the Y direction for a total length of 10 meters and 8 bays in the X direction for a total length of 40 meters. Each of the eight floor is 3 meters high for a total elevation of 24 meters.
The seismic behaviour of the buildings was analysed before any intervention and after the introduction of an "exoskeleton", a steel frame with parietal cross braces designed to resist to wind loads and connected to the building with SMADs.
The nonlinear analyses considered three different areas - zone 1, 2 and 3 - within the Italian territory, characterized by different levels of seismicity: zone 1 corresponds to Brescia (Brescia), zone 2 to Borgo Tossignano (Bologna) and zone 3 to Aielli (L'Aquila). The pushover analysis evaluated the capacity of the buildings at the different performance levels, defined by the Italian code (2008) and the FEMA 356 (2000), applying horizontal loads for two orthogonal directions, for two load distributions, for positive or negative eccentricity, with eight combinations for each building in total in each of the three seismic zone. The time history analysis assessed the interstory drift of a control point in relation to the the Italian code (2008) using seven spectrum compatible accelerograms generated for each of the three zones with the software SIMQKE.
The model required the introduction of different groups of hinges in relation to the collapse modes for the columns – combined compressive and bending failure and shear failure –, for the beams – bending failure and shear failure – and for the panel, described with axial hinges.

$\gamma_m = 1{,}8$
$f'_c = f_x = 9500$
$E_m = 1000 \cdot f_x \cdot \gamma_m = 550 \cdot f_x = 5225000$
G_m =2090000
$E_c = 31476000$

Parameter	Value
H (cm)	300
h (cm)	270
l (cm)	460
t (cm)	40
θ (°)	30
θ (rad)	0,53
d (cm)	533
I col (cm4)	67500
λ1H	5,04
a (cm)	49
A openings (cm2)	-
A panel (cm2)	124200
R1	1
R2	1
l col (cm)	54,01
θ col (rad)	0,439
l beam (cm)	49,02
θ beam (rad)	1,496
K1 (kN/cm)	14243
Fy (kN)	368
Sy (cm)	0,026
K2 (kN/cm)	1916
Fm (kN)	478,4
Sm (cm)	0,083
Fr (kN)	36,8
Sr (cm)	1,7

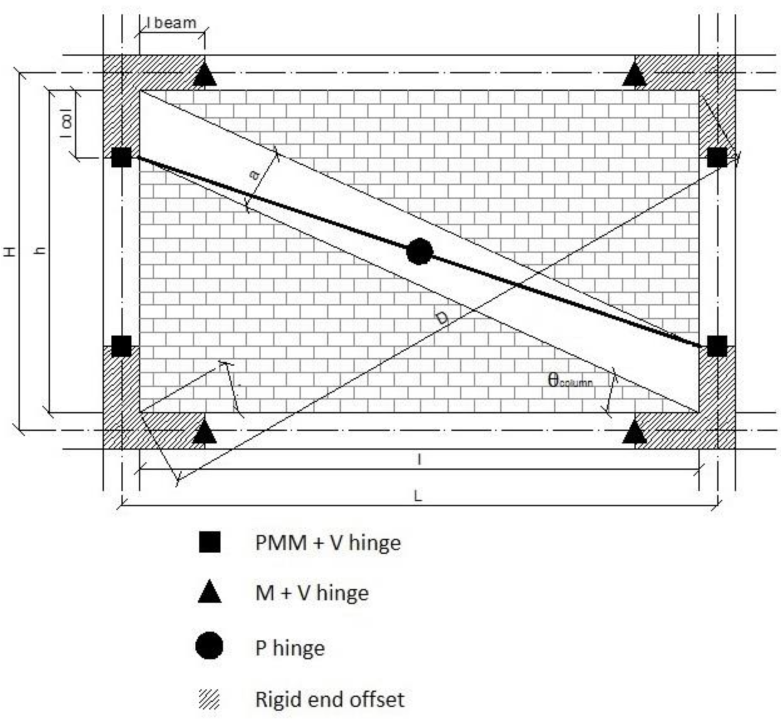


Table 8.2
Geometrical features of the equivalent struts and definition of the plastic hinges.

The results of pushover and time history analyses are promising in all the three seismic areas.
First of all it is worth to notice how the SMADs have been introduced in both the two principal directions of development of the structure in order to reduce the lateral displacements.
The distribution of the devices is regular, with an equal number on every floors and following the span of the frame structure. The next step would consider an optimization in the use of the material, reducing the costs connected to the shape memory alloys.
In relation to the three typologies of SMAD verified, it appears clear that the pretension increases the ability of the device to limit the lateral displacement dissipating more energy throughout the hysteretic cycles, and, in general, this behaviour results more efficient when the lateral loading is higher.
The following data sheets are connected to the data obtained from the analysis using the software SAP2000.
The steel frame has been designed elastically to resist to static and wind load and it is equipped with steel braces, located to allow the better exploitation of the new spaces within the "exoskeleton" and to allow the greater visual landscape. A progressive optimization of this structural scheme can be realized starting from the results of the nonlinear analyses.

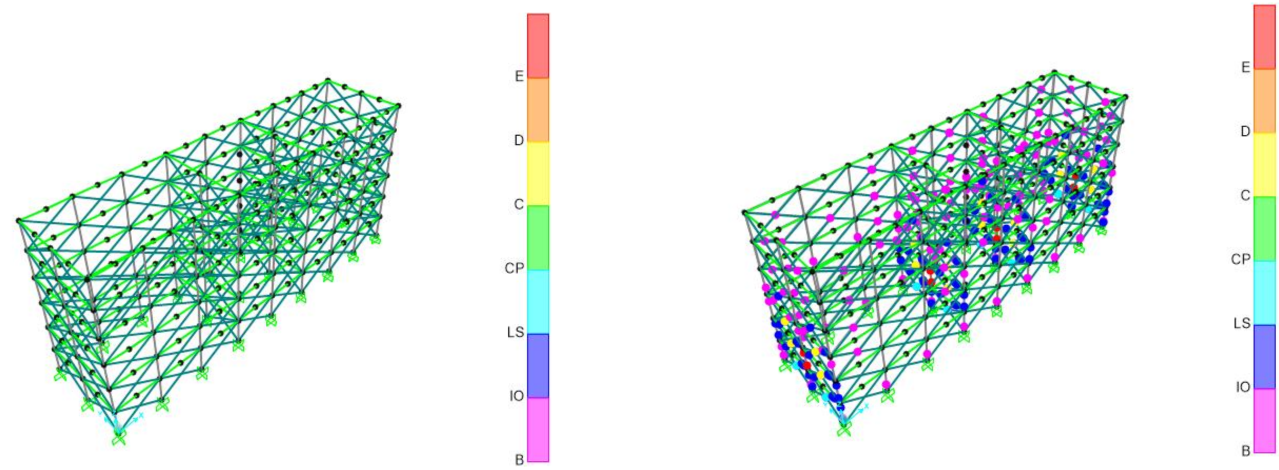


Figure 8.7
Pushover analysis (Y+ mode) on an existing building located in zone 3. On the left step 0, on the right last step.

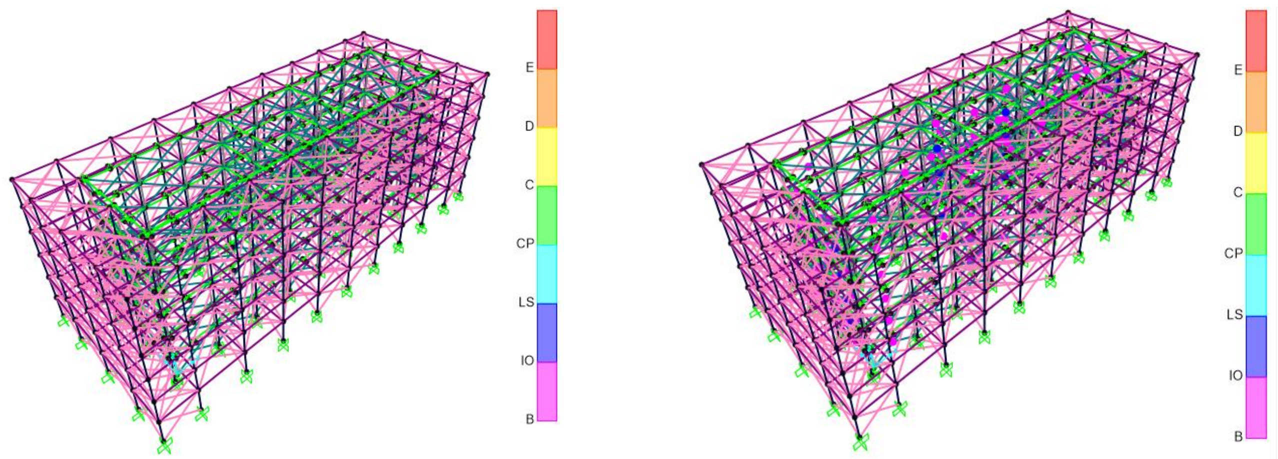
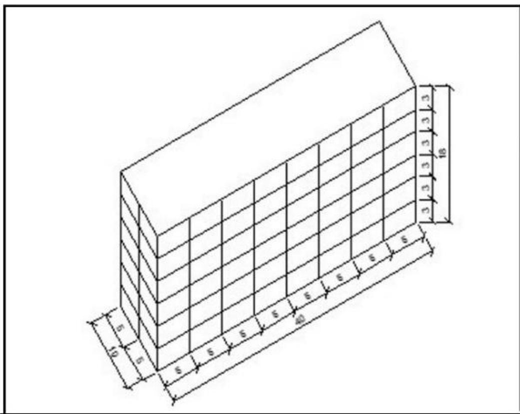
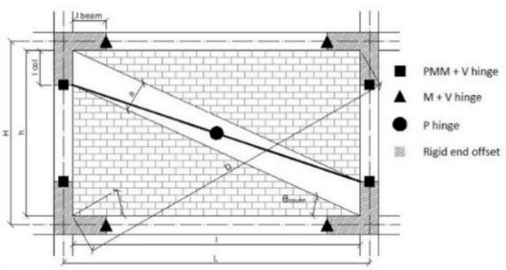
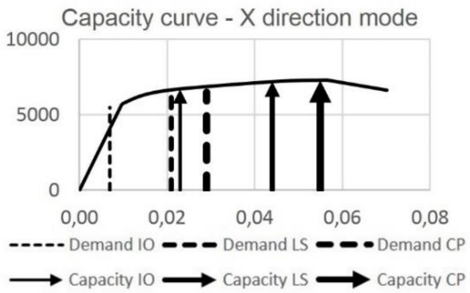


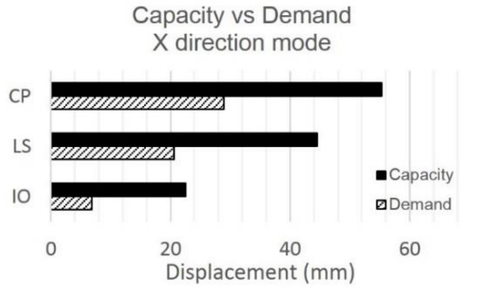
Figure 8.8
Pushover analysis (Y+ mode) on an existing building located in zone 3 with the "adaptive exoskeleton", SMAD type 05_10. On the left step 0, on the right last step.

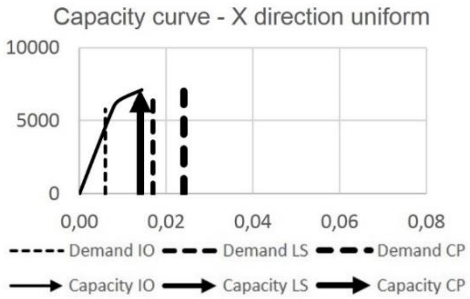


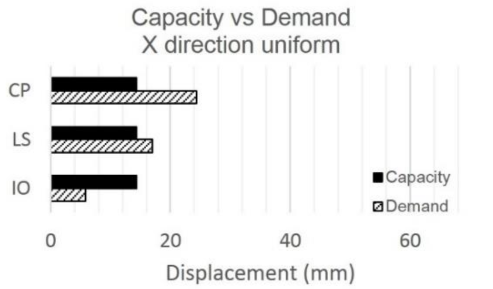


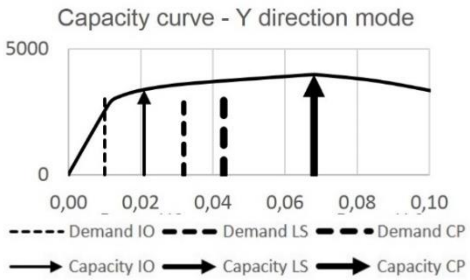
H (cm)	300	a (cm)	49
h (cm)	270	l col (cm)	54,01
l (cm)	460	θ col (rad)	0,439
t (cm)	40	l beam (cm)	49,02
D (cm)	533	θ beam (rad)	1,496

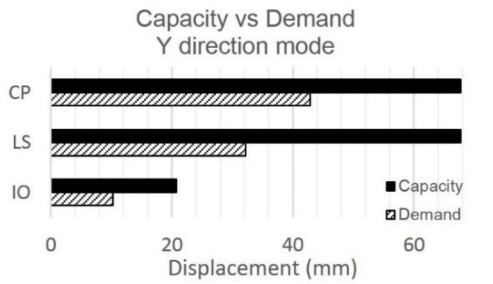


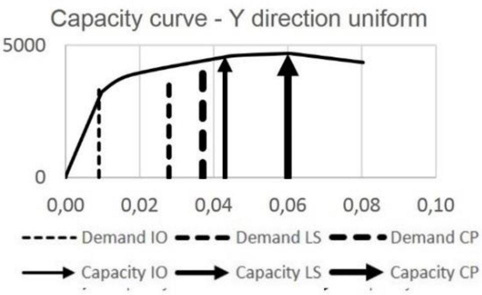


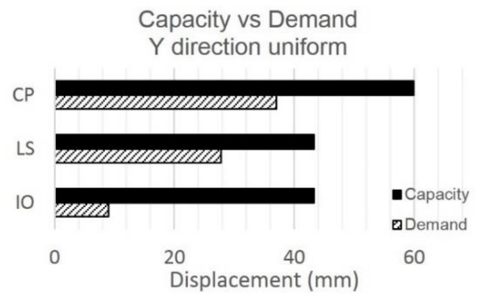


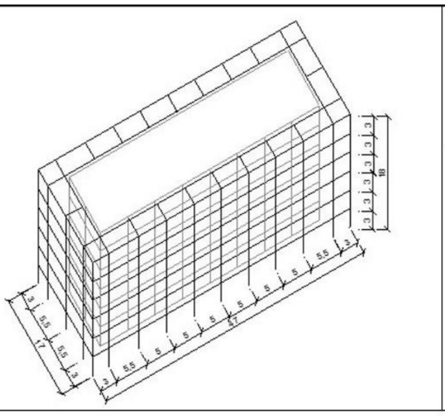


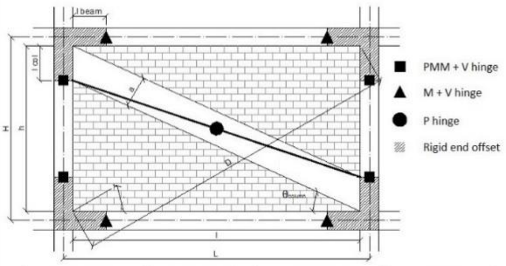




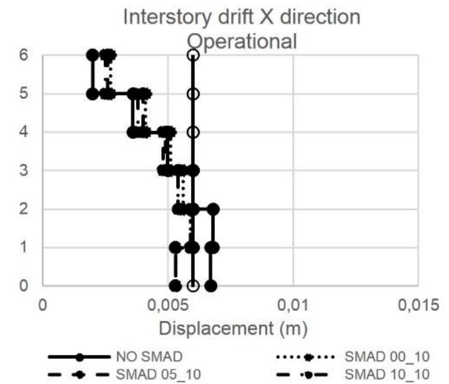


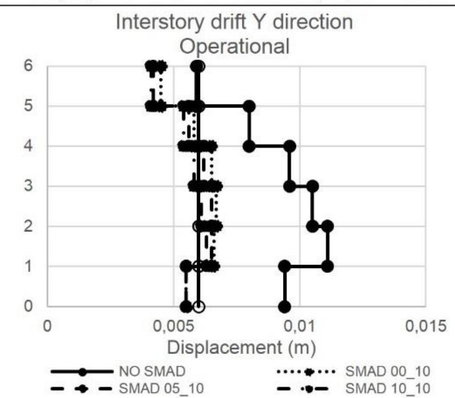


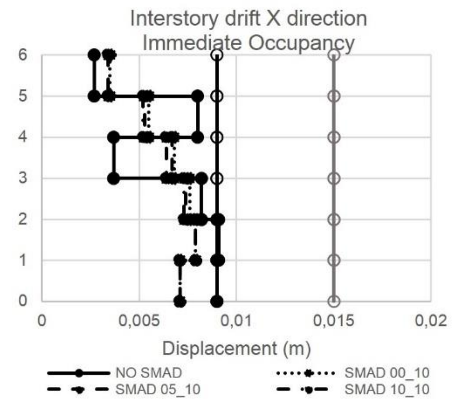


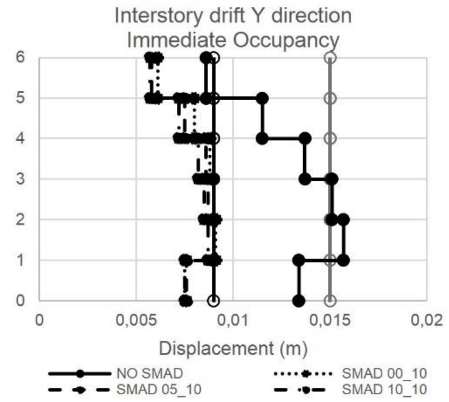


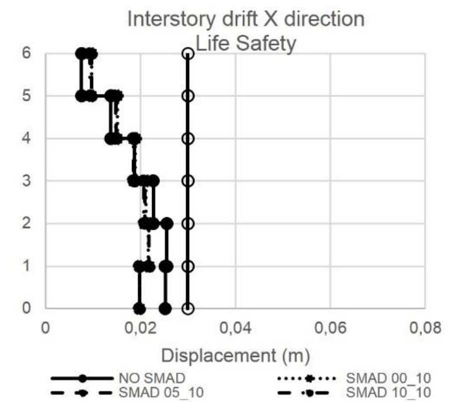
H (cm)	300	a (cm)	49
h (cm)	270	l col (cm)	54,01
l (cm)	460	θ col (rad)	0,439
t (cm)	40	l beam (cm)	49,02
D (cm)	533	θ beam (rad)	1,496

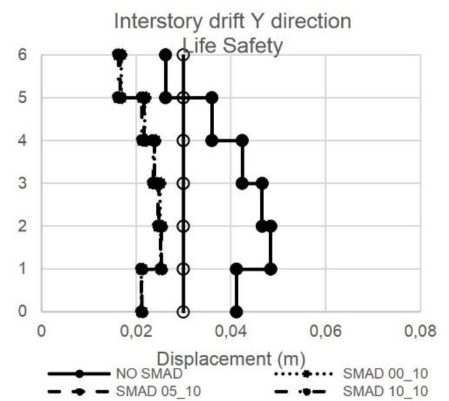


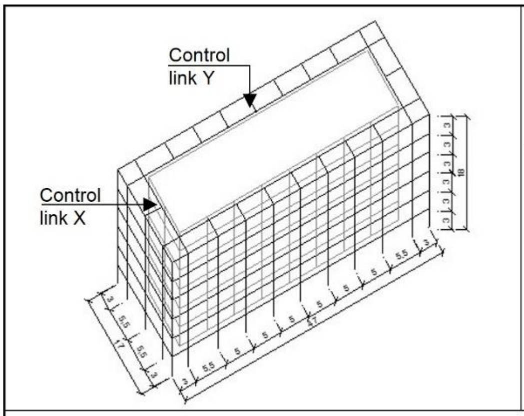


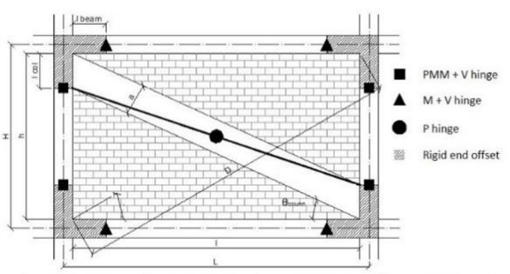




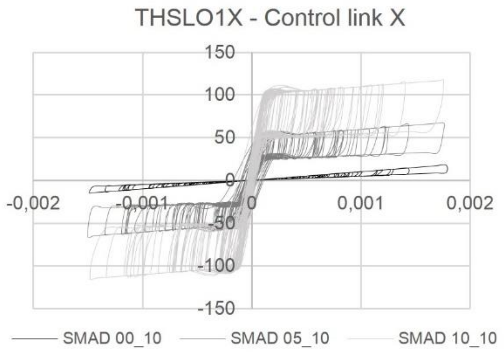


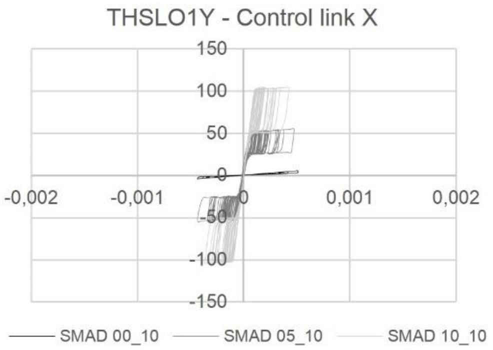


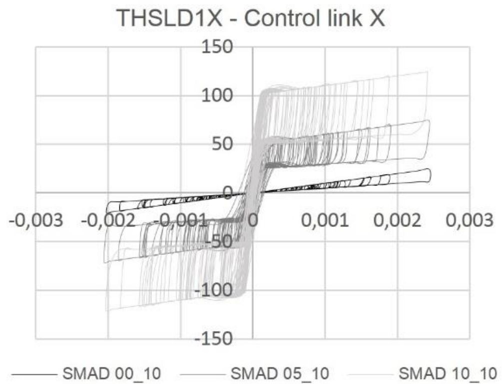


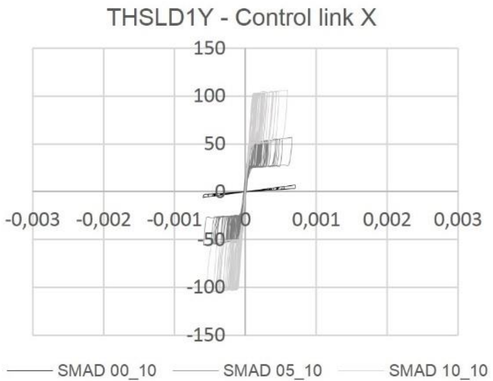


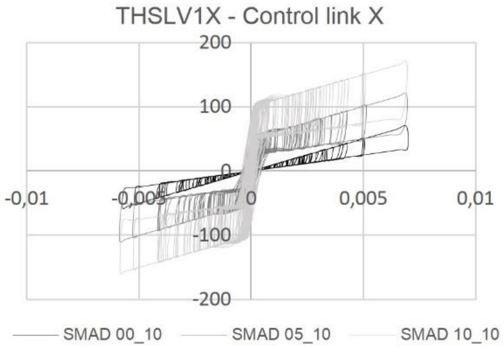
H (cm)	300	a (cm)	49
h (cm)	270	l col (cm)	54,01
l (cm)	460	θ col (rad)	0,439
t (cm)	40	l beam (cm)	49,02
D (cm)	533	θ beam (rad)	1,496

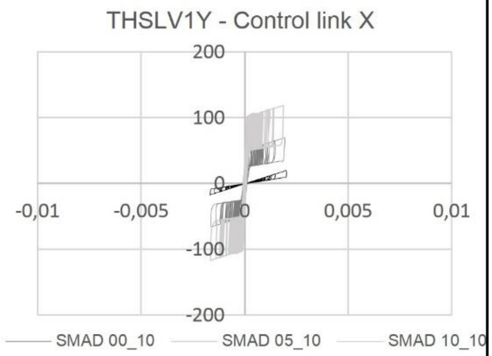


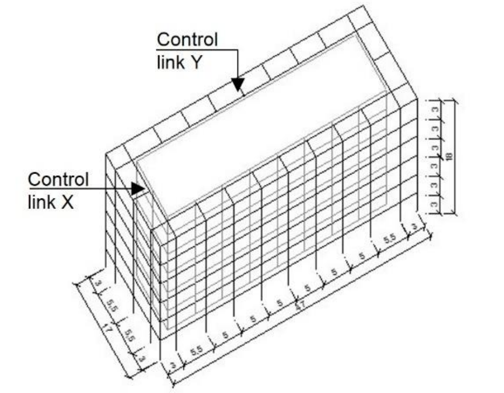


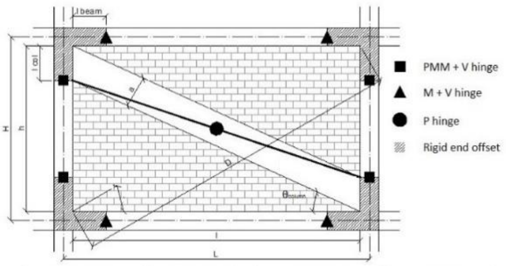




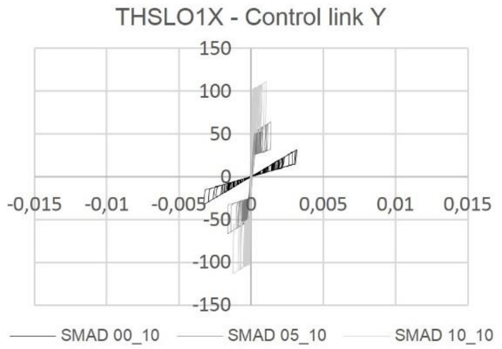


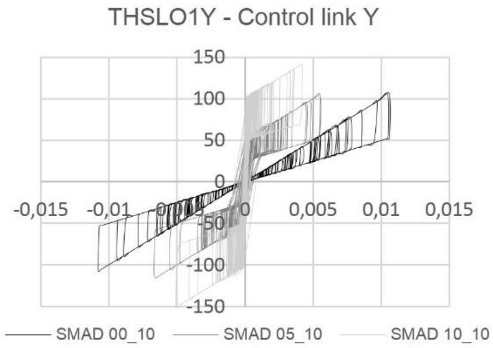


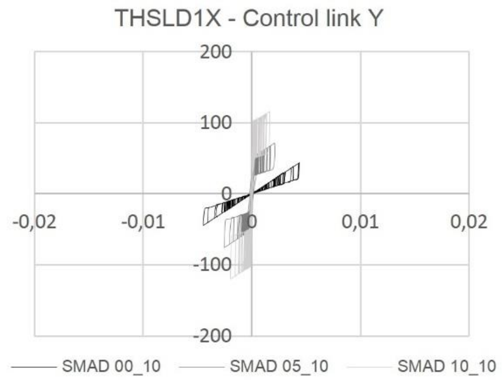


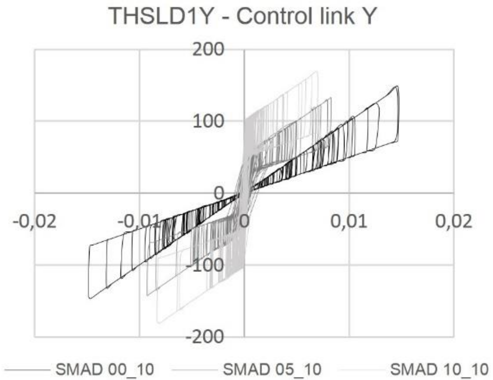


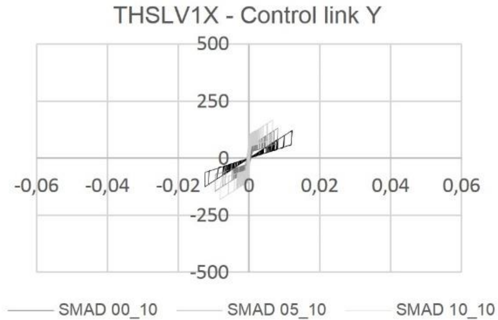
H (cm)	300	a (cm)	49
h (cm)	270	l col (cm)	54,01
l (cm)	460	θ col (rad)	0,439
t (cm)	40	l beam (cm)	49,02
D (cm)	533	θ beam (rad)	1,496

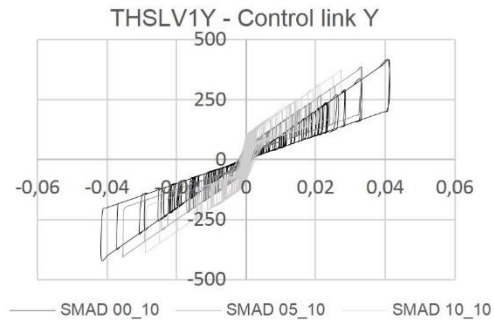


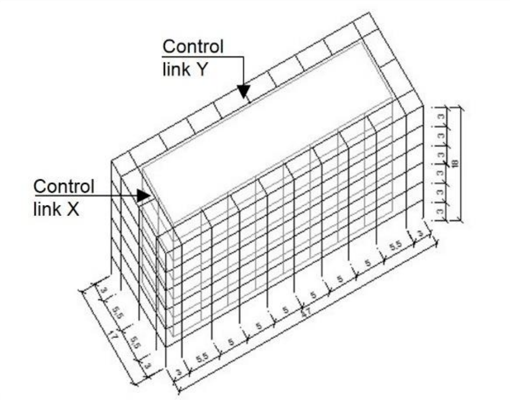


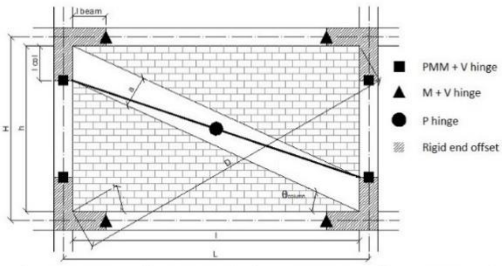




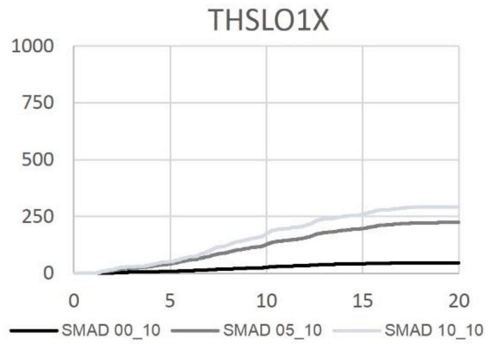


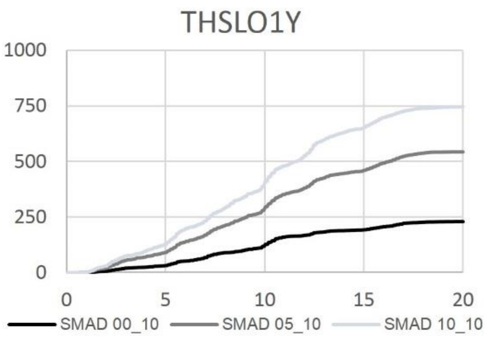


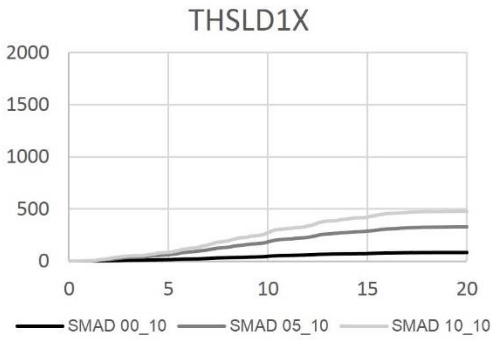


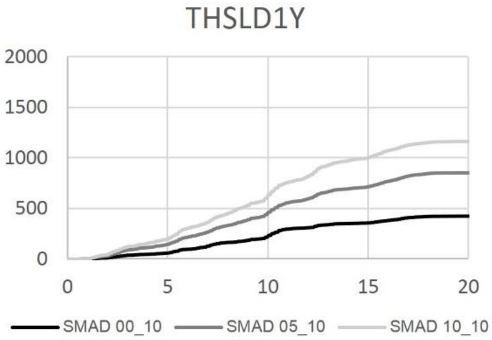


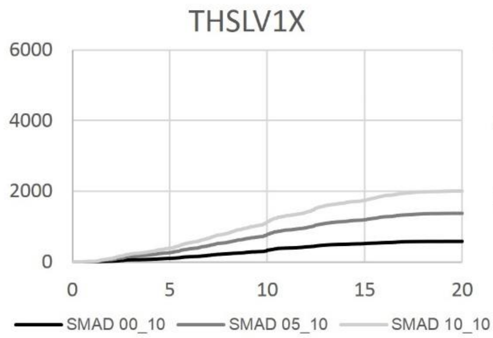
H (cm)	300	a (cm)	49
h (cm)	270	l col (cm)	54,01
l (cm)	460	θ col (rad)	0,439
t (cm)	40	l beam (cm)	49,02
D (cm)	533	θ beam (rad)	1,496

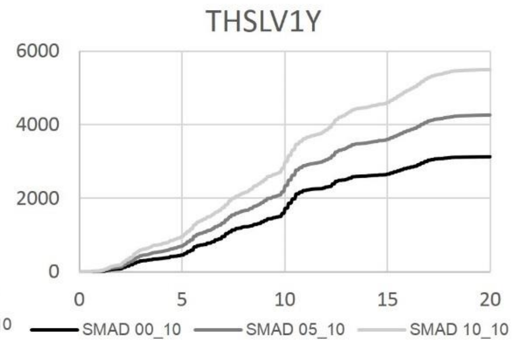


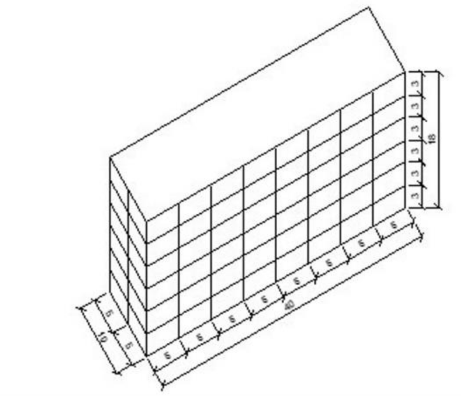


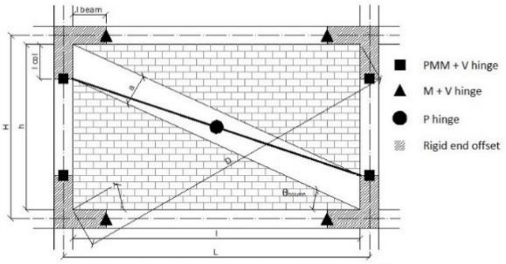




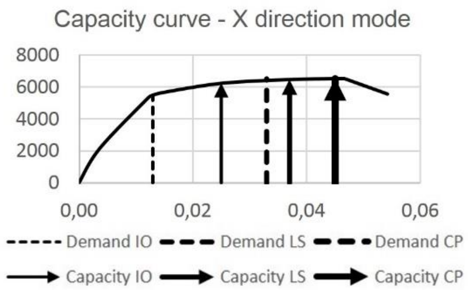


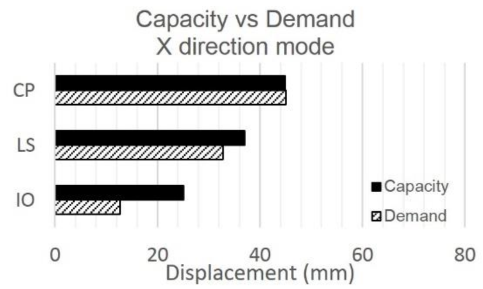


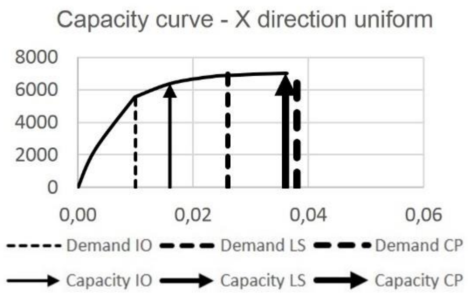


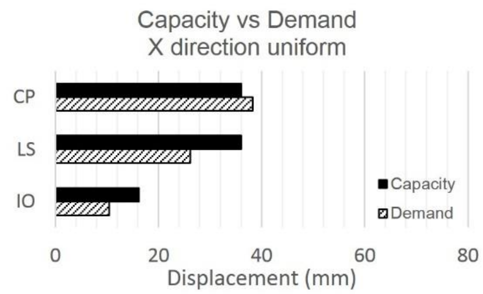


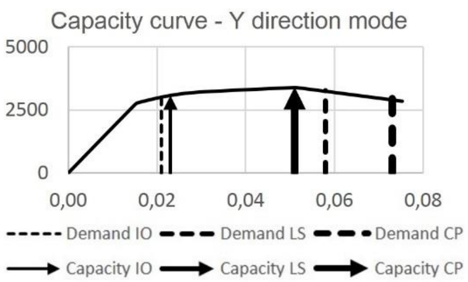
H (cm)	300	a (cm)	49
h (cm)	270	l col (cm)	54,01
l (cm)	460	θ col (rad)	0,439
t (cm)	40	l beam (cm)	49,02
D (cm)	533	θ beam (rad)	1,496

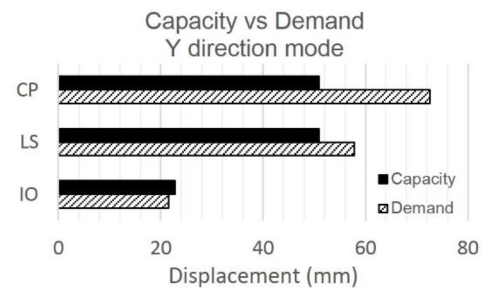


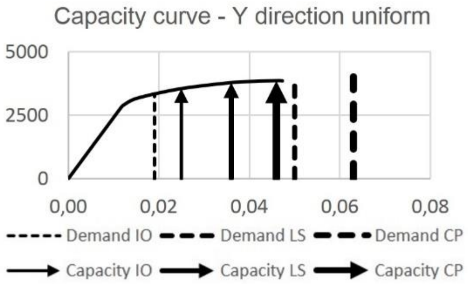


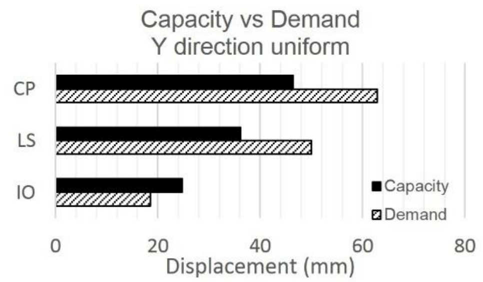


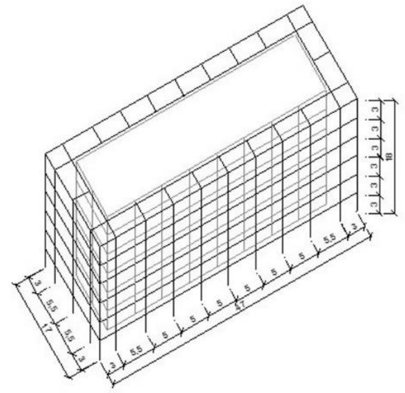


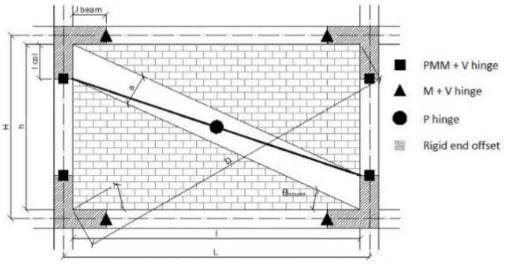




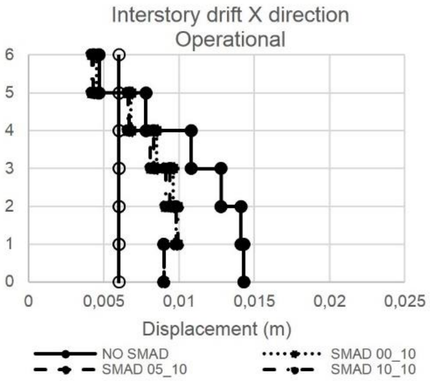


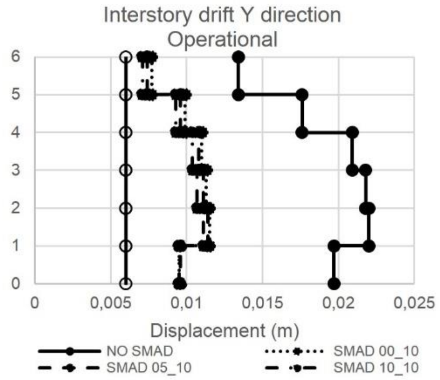


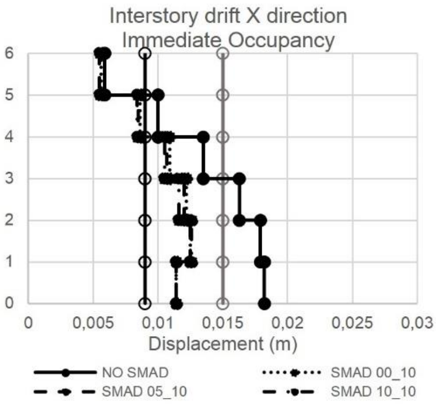


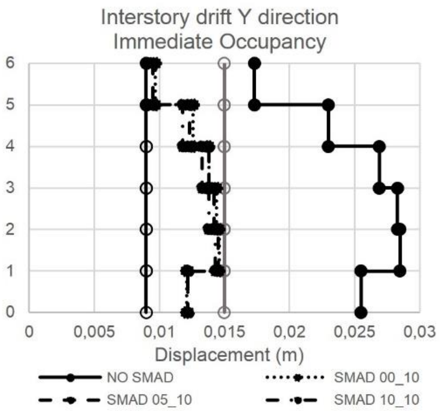


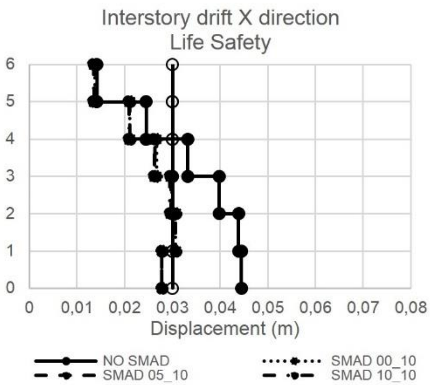
H (cm)	300	a (cm)	49
h (cm)	270	l col (cm)	54,01
l (cm)	460	θ col (rad)	0,439
t (cm)	40	l beam (cm)	49,02
D (cm)	533	θ beam (rad)	1,496

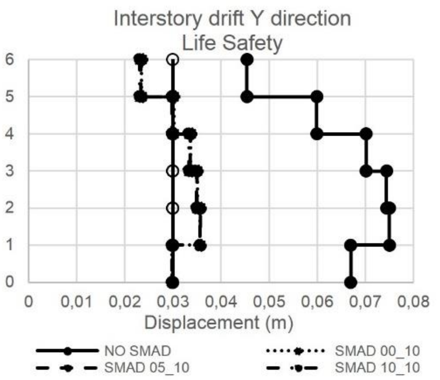


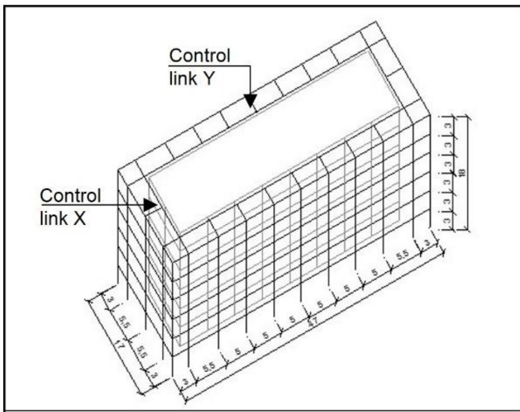


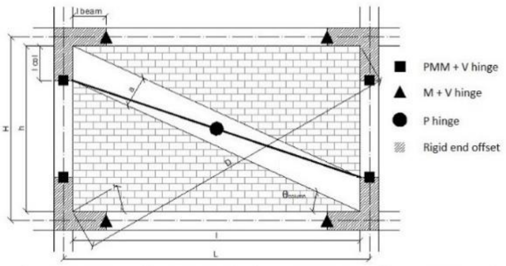






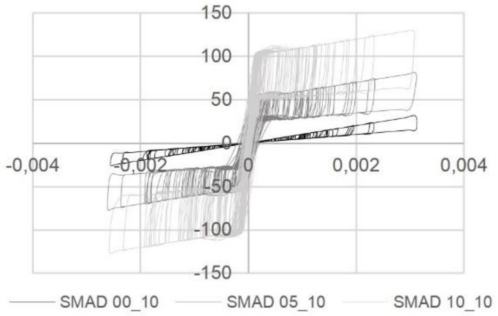




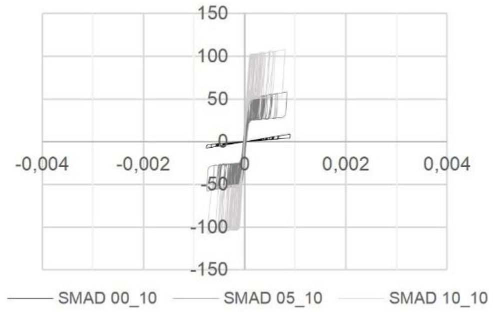


H (cm)	300	a (cm)	49
h (cm)	270	l col (cm)	54,01
l (cm)	460	θ col (rad)	0,439
t (cm)	40	l beam (cm)	49,02
D (cm)	533	θ beam (rad)	1,496

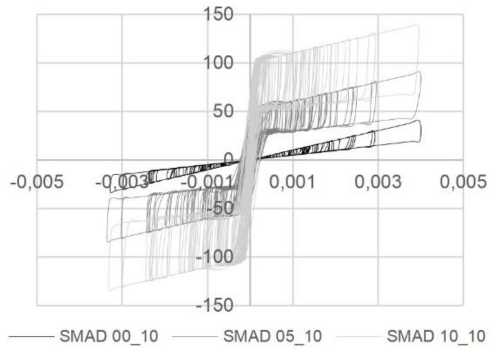
THSLO1X - Control link X



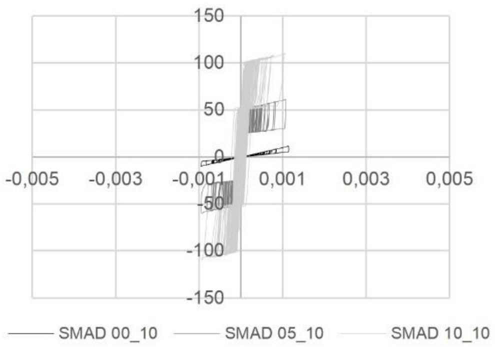
THSLO1Y - Control link X



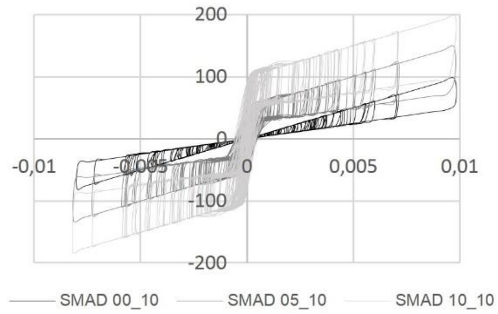
THSLD1X - Control link X



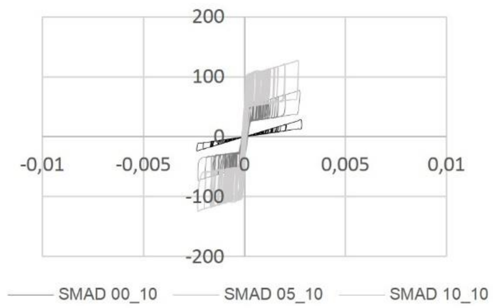
THSLD1Y - Control link X

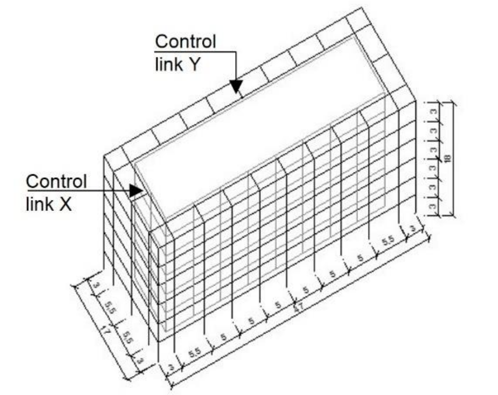


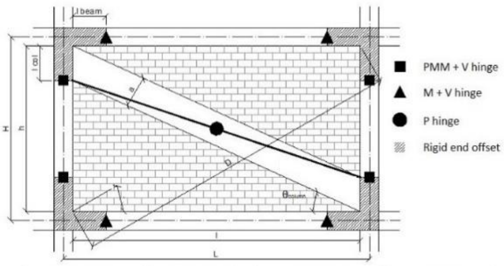
THSLV1X - Control link X



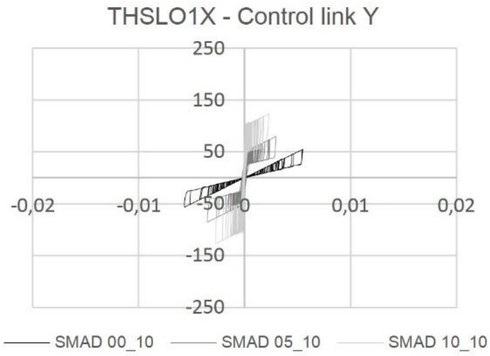
THSLV1Y - Control link X

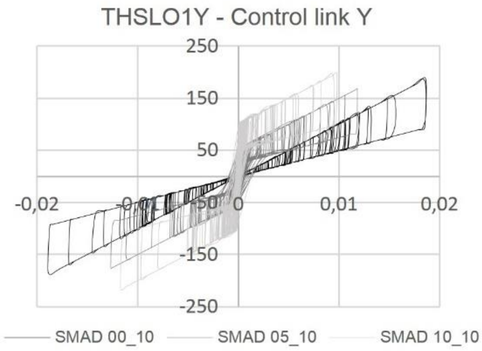


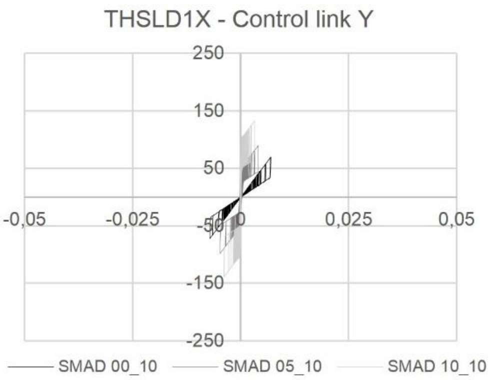


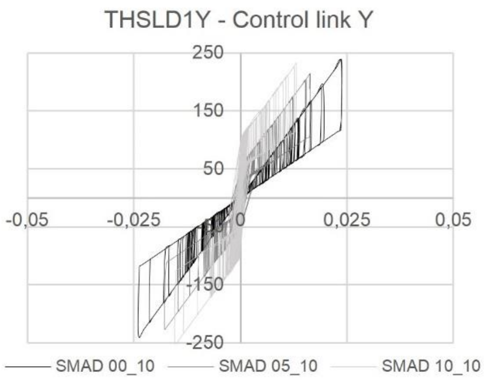


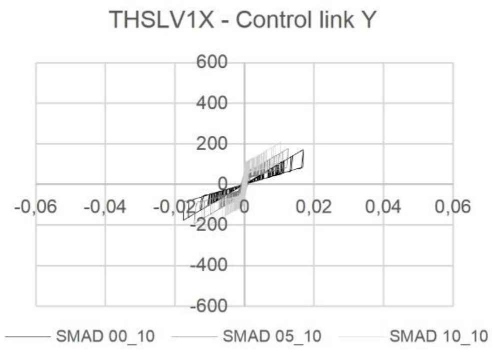
H (cm)	300	a (cm)	49
h (cm)	270	l col (cm)	54,01
l (cm)	460	θ col (rad)	0,439
t (cm)	40	l beam (cm)	49,02
D (cm)	533	θ beam (rad)	1,496

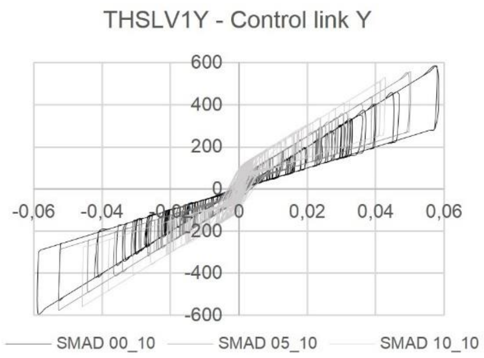


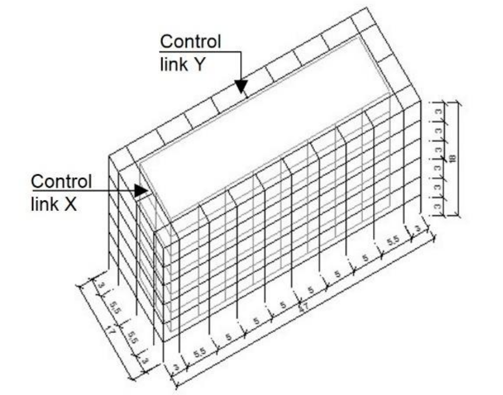


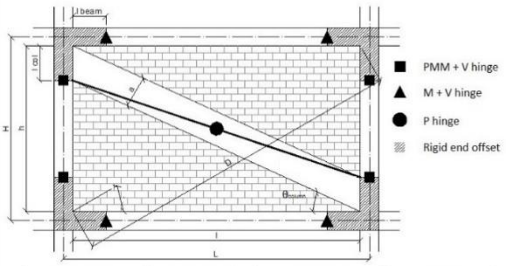




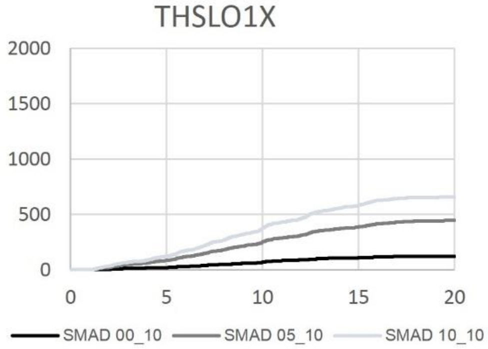


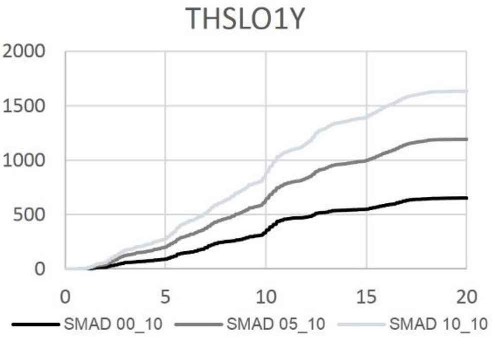


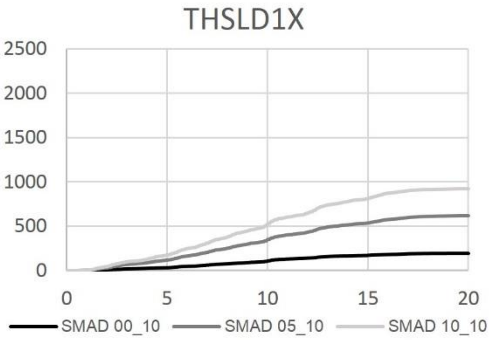


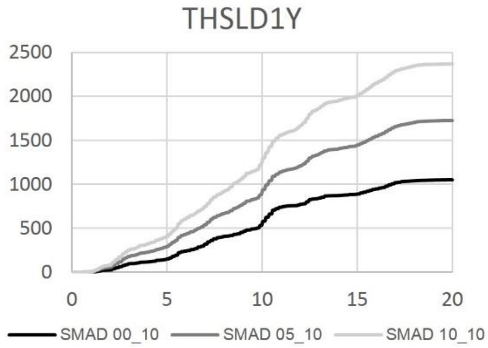


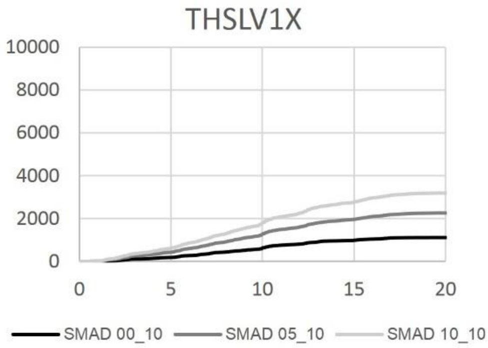
H (cm)	300	a (cm)	49
h (cm)	270	l col (cm)	54,01
l (cm)	460	θ col (rad)	0,439
t (cm)	40	l beam (cm)	49,02
D (cm)	533	θ beam (rad)	1,496

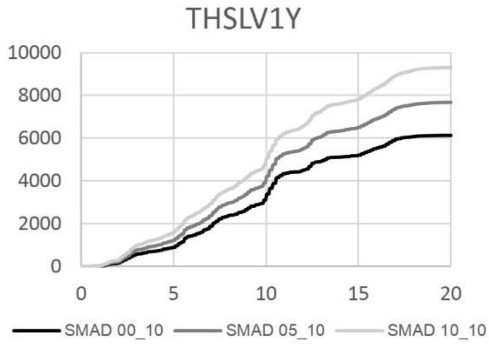


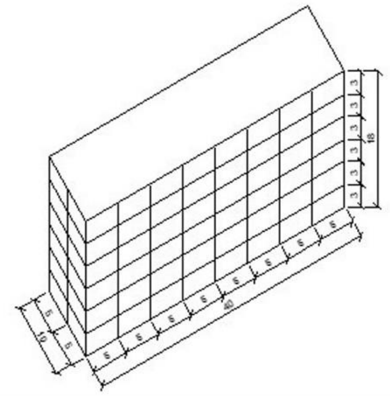


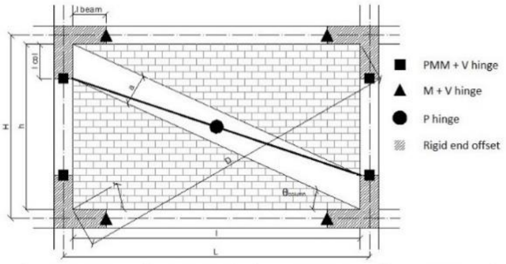




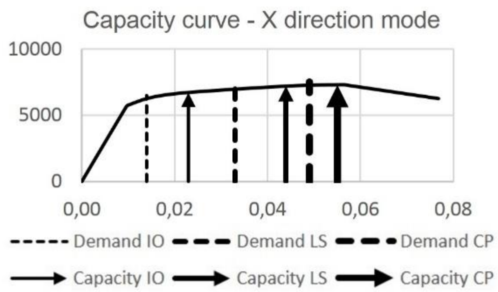


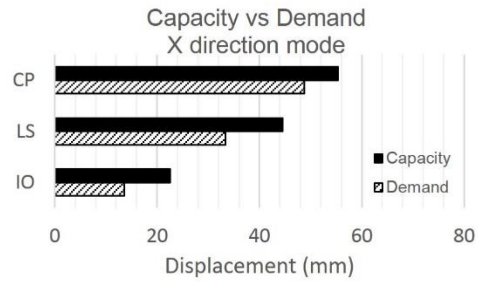


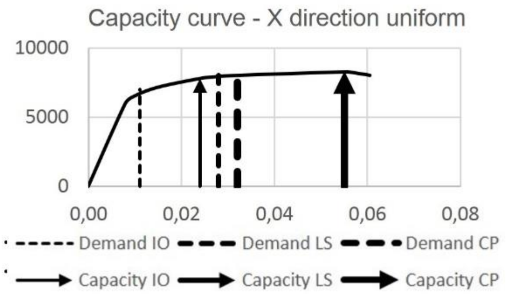


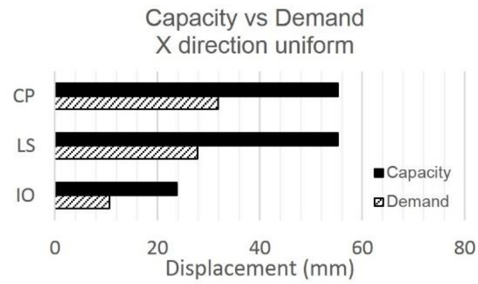


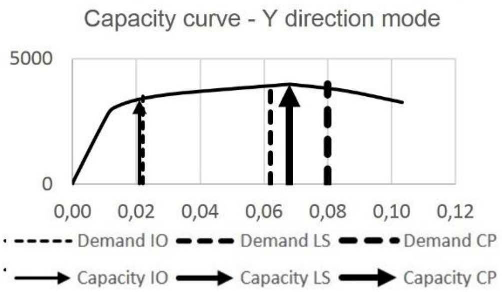
H (cm)	300	a (cm)	49
h (cm)	270	l col (cm)	54,01
l (cm)	460	θ col (rad)	0,439
t (cm)	40	l beam (cm)	49,02
D (cm)	533	θ beam (rad)	1,496

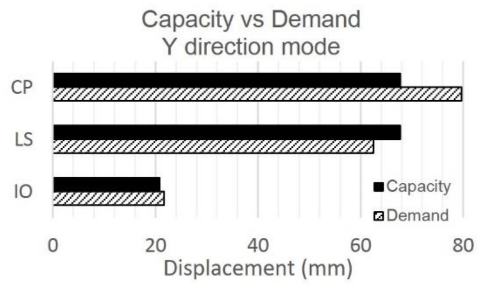


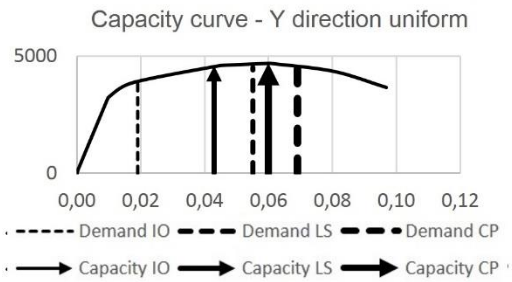


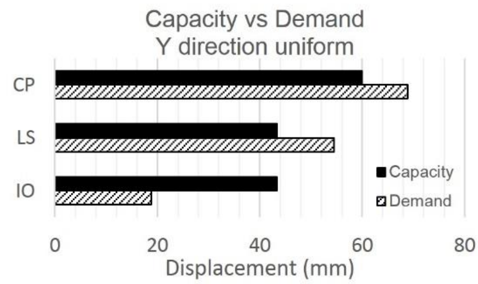


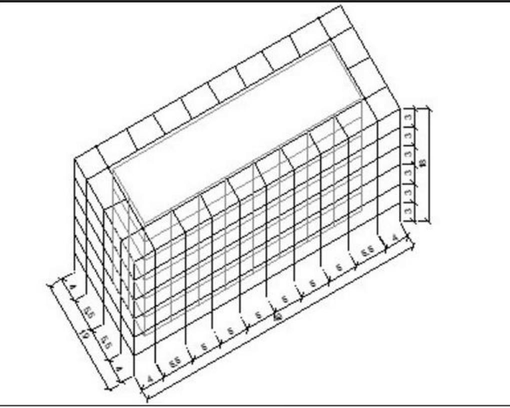


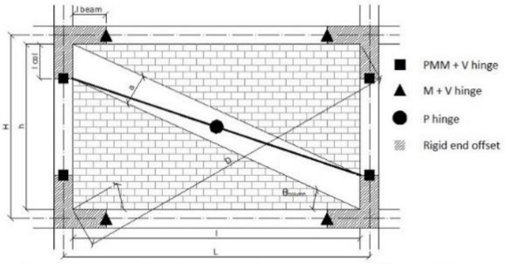




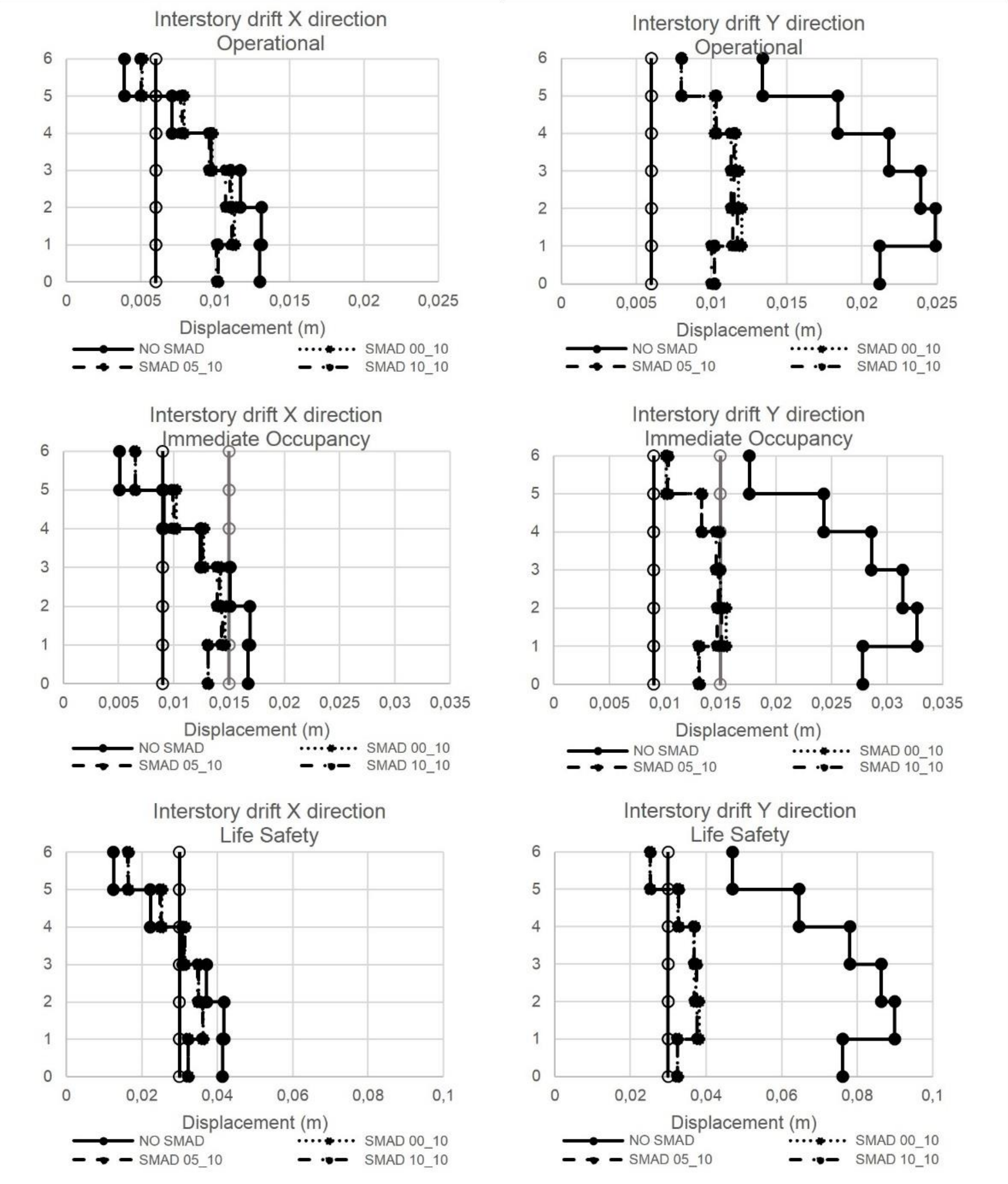


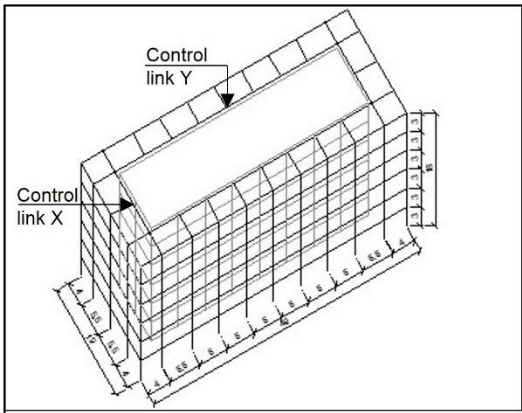


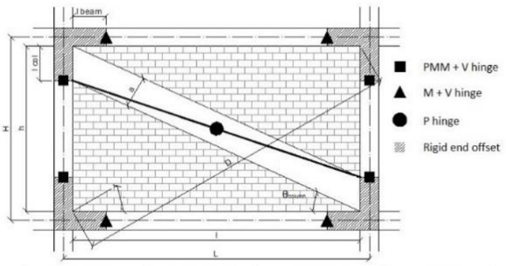




H (cm)	300	a (cm)	49
h (cm)	270	l col (cm)	54,01
l (cm)	460	θ col (rad)	0,439
t (cm)	40	l beam (cm)	49,02
D (cm)	533	θ beam (rad)	1,496

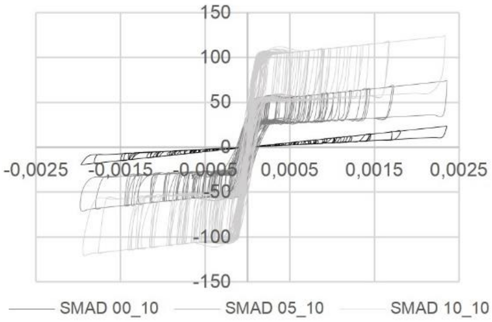






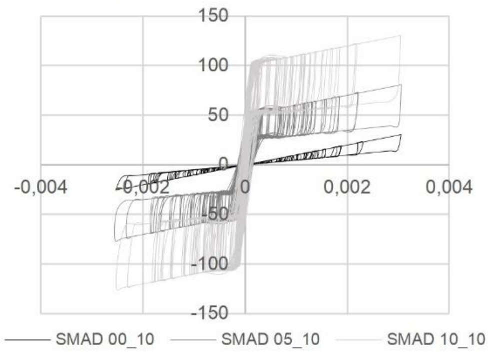
H (cm)	300	a (cm)	49
h (cm)	270	l col (cm)	54,01
l (cm)	460	θ col (rad)	0,439
t (cm)	40	l beam (cm)	49,02
D (cm)	533	θ beam (rad)	1,496

THSLO1X - Control link X



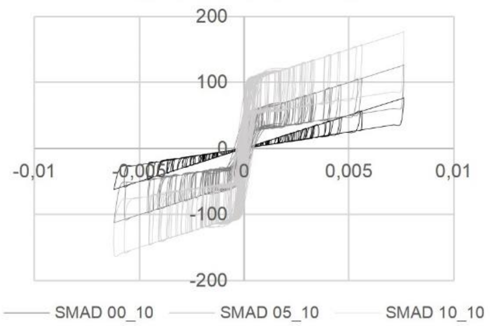
THSLO1Y - Control link X

THSLD1X - Control link X

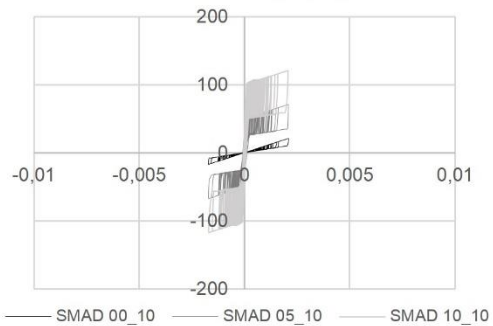


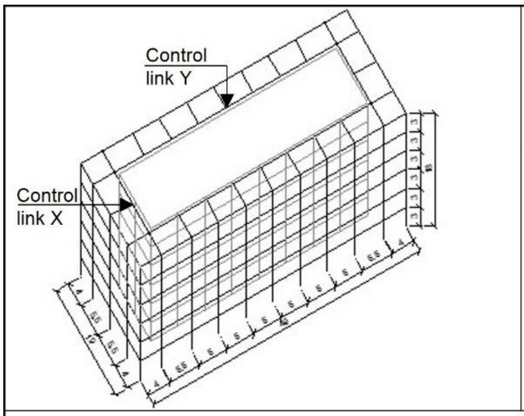
THSLD1Y - Control link X

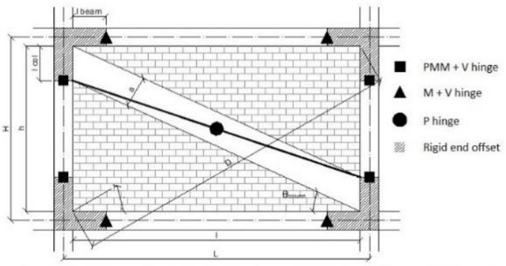
THSLV1X - Control link X



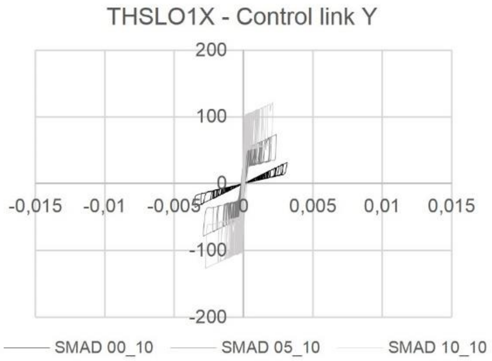
THSLV1Y - Control link X

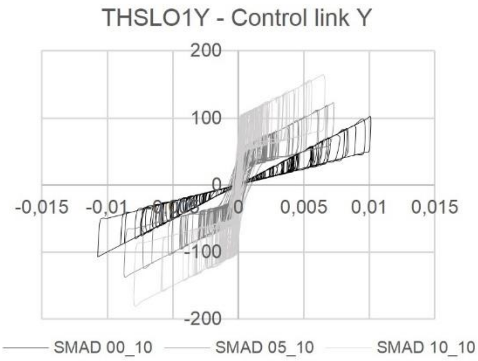


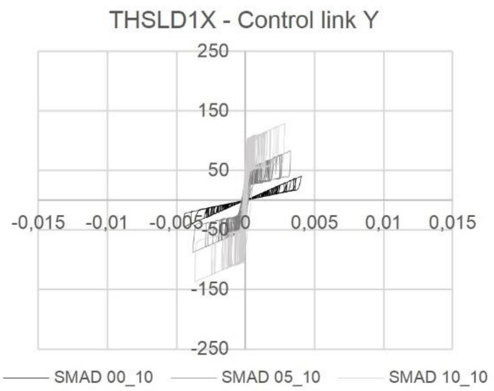


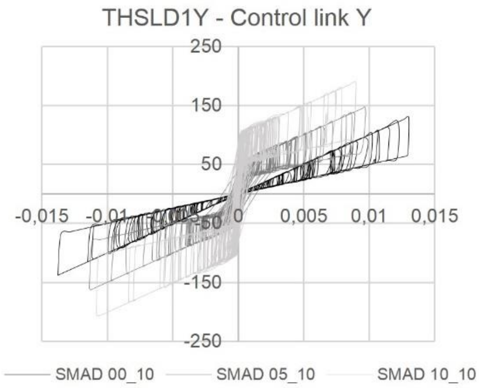


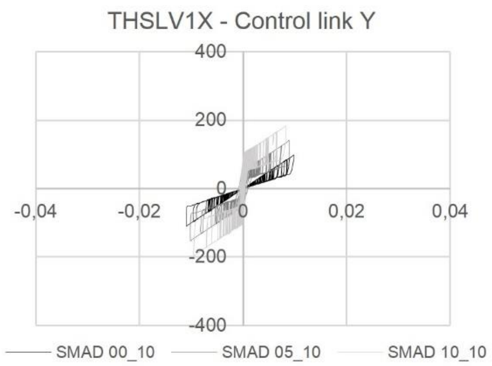
H (cm)	300	a (cm)	49
h (cm)	270	l col (cm)	54,01
l (cm)	460	θ col (rad)	0,439
t (cm)	40	l beam (cm)	49,02
D (cm)	533	θ beam (rad)	1,496

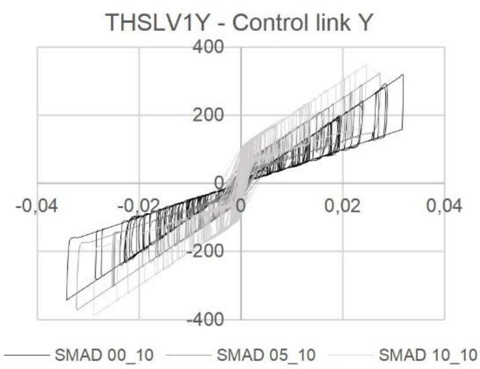


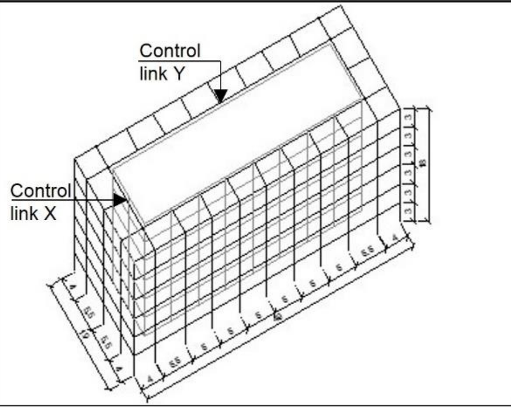


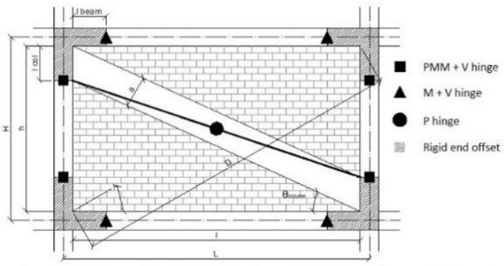




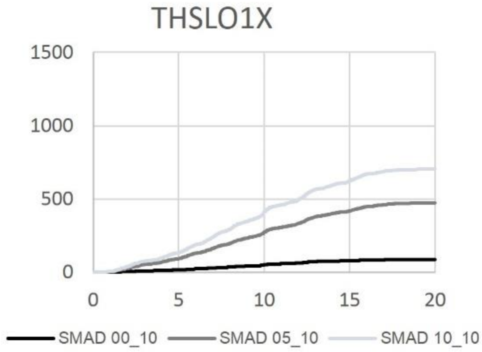


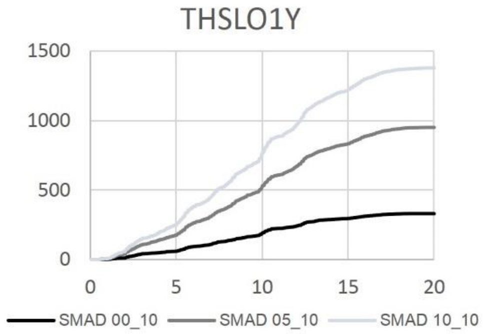


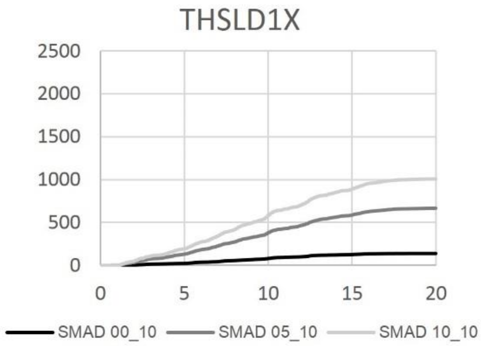


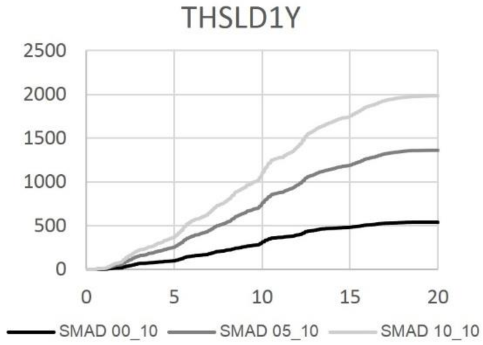


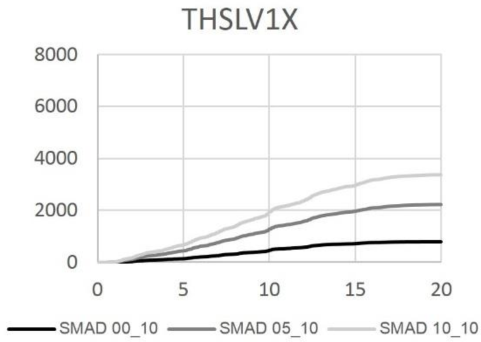
H (cm)	300	a (cm)	49
h (cm)	270	l col (cm)	54,01
l (cm)	460	θ col (rad)	0,439
t (cm)	40	l beam (cm)	49,02
D (cm)	533	θ beam (rad)	1,496

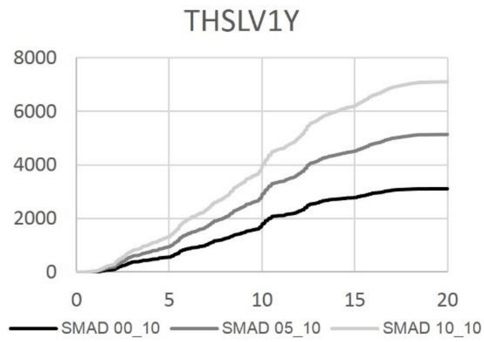












8.3 Masonry type

A possible approach to model the structural system is to discretize the masonry constitutive elements (units, mortar) into a certain number of finite elements, which, with suitable constitutive non-linear laws, can be a powerful analysis tool. The drawbacks of this method are the high computational effort, often unsustainable for professional practice, and issues such as the potential mesh-dependency and the calibration of the input parameters (Sabatino & Rizzano, 2010).

A second approach is based on the adoption of "equivalent frames", a method very common to structural engineers. An assemblage of linear elements describes the structure: the first ones, describing piers, are the vertical resistant elements for both dead loads and seismic forces, and the horizontal ones, the spandrels, are secondary elements able to couple the piers in case of seismic loads.

Piers and spandrels are connected by rigid offsets and each element is modelled using constitutive laws and plastic hinges, in order to take into account mechanical non-linearity. This approach introduces strong simplifications, and hence its accuracy depends strongly on the consistency between the hypotheses and the actual structure (Sabatino & Rizzano, 2010).

In order to deal with a large stock of buildings, such as in the case of social housing estates, the adoption of FEM models becomes unconvenient from the practical point of view, while the equivalent frame model can be an effective tool if its main issues are carefully taken into account (Sabatino & Rizzano, 2010).

Methods as POR (Braga & Dolce, 1982), and its evolutions (Fusier & Vignoli, 1993), propose an incremental simplified static nonlinear analysis, introducing the hypothesis of in-plane collapse and rigid floors.

Within this thesis, the masonry type will be modelled using the Simplified Analysis of Masonry buildings (SAM), conceived for the global analysis of new and existing masonry buildings, in which the resisting mechanism is governed by in plane response of walls. This analysis is meaningful if proper means, such as ties and/or ring beams, prevent local and global out-of-plane collapses, which otherwise would occur prematurely at low seismic intensities (Magenes, 2000).

The approach was developed first for plane structures (Magenes and Della Fontana, 1998), and subsequently extended to three-dimensional buildings.

To analyse three-dimensional buildings, the plane model was extended by formulating the constitutive laws of piers and spandrels in three dimensions, assuming an independent behaviour of the pier or spandrel element in the two principal orthogonal planes parallel to the element axis. The out-of-plane behaviour is modelled similarly to the in-plane behaviour. Composite walls (i.e. flanged walls or orthogonal intersecting walls) are decomposed in simple walls with rectangular cross section. If the intersecting walls are effectively bonded, it is possible to simulate the bond defining appropriate rigid offsets and imposing the continuity of displacements at the ends of rigid offsets at the floor levels (Magenes, 2000).

In the SAM, developed since 1996 by Magenes and Calvi (1997), and then modified by Magenes and Della Fontana (1998), each wall is schematized with an equivalent frame, composed by columns representing the piers, beams representing the spandrels, and rigid offsets describing the joints (Bucchi et al., 2013).

This scheme is acceptable when the geometry of the walls and the distribution of openings are regular and it requires less computational effort (Magenes, 2000).

Both the pier and the spandrel are modelled considering an elastic-plastic behaviour with equivalent resistance defined as a function of the flexural and shear behaviour and a deformation limit; the plasticity is modelled by using plastic hinges, activating when a threshold is overcame (Bucchi et al., 2013).

The analysis is performed under displacement control, as this is the only effective way to predict the complete pushover curve of the wall, as requested by the nonlinear static procedures previously described.

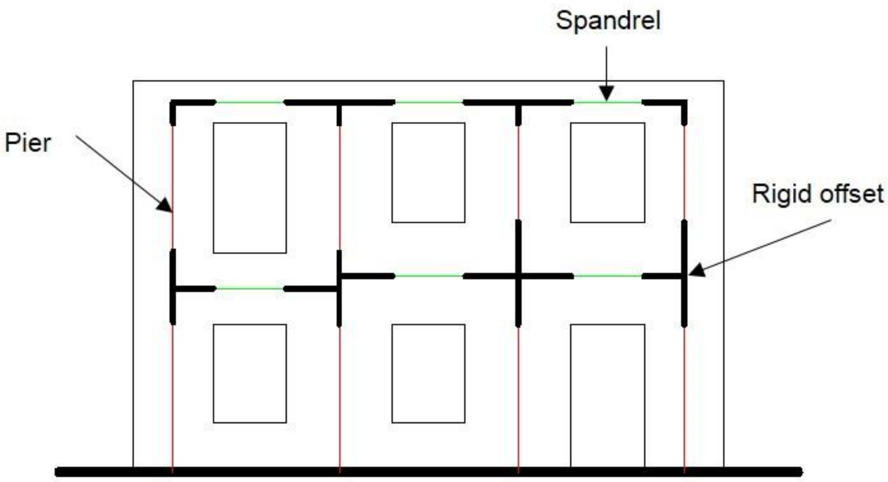


Figure 8.9
Modelling of the structural wall with an equivalent frame.

Piers are modelled with linear elements with vertical axis, located in correspondence of the baricentral axis of the panel. Their total length equal to the difference between the quota of the barycentric planes of the floors comprising the structural element.
At the two ends of each linear elements, two joints define the connection with adjacent parts.
The model defines a central deformable area, with finite strength, and two infinitely rigid extremities. The proportion between the parts is defined in relation to the different deformability of the masonry comprised between the two adjacent openings. The deformable area can be defined with the relation:

$$H_{eff} = h' + \frac{1}{3} L \frac{H-h'}{h'} \qquad (23)$$

Where H is the net interstory height, L is the length of the panel and h' a parameter defined in relation to the different configuration of opening as in figure 8.10.

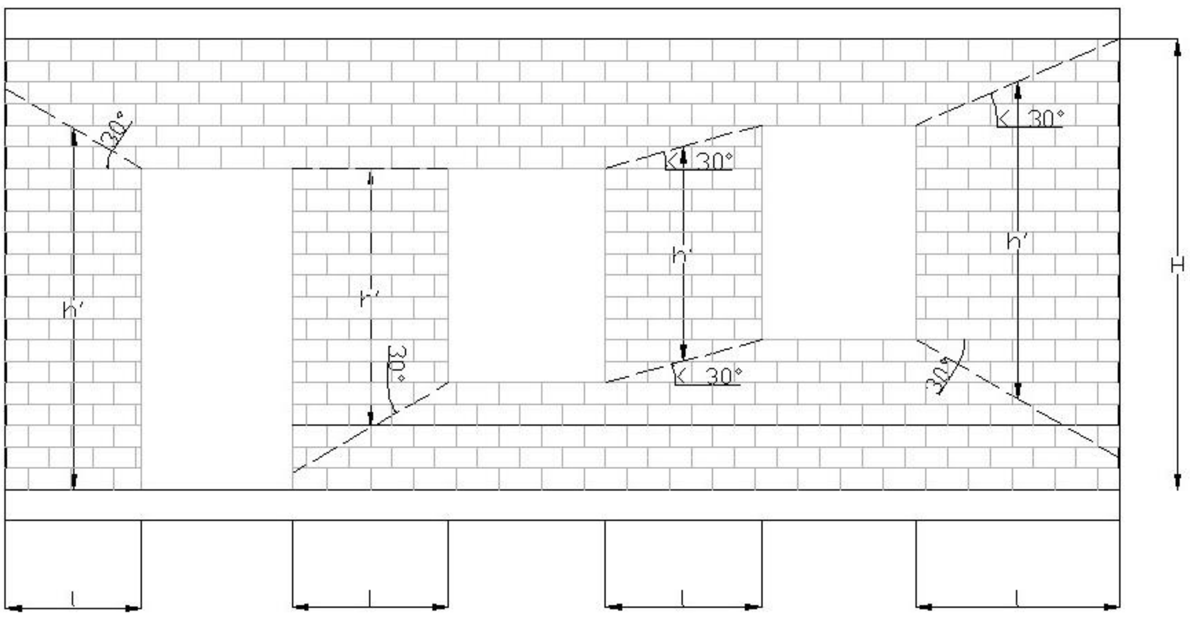


Figure 8.10
Definition of the parameter h' in relation to the different configuration of openings.

The panels can experience in-plane collapse following different medes, each one characterized by a different value of ultimate shear.
The effective mechanism is associated by a combination of factors, such as the geometry of the panel, the axial loading, the material properties and the boundary constraints.
Experience shows that the most realistic situation is constituted by a combination of cases, where one mechanism overlaps to the first one.
Considering the constraints, the parameter used within the SAM method is the shear factor α_v defined as:

$$\alpha_v = \frac{M}{V \cdot L} = \frac{H_0}{L} \qquad (24)$$

With H_0 the distance where the moment of the element is zero, from the considered extremity.

Flexural or "rocking" failure in piers occurs when the moment *M* at any of the end sections of the effective pier length attains the ultimate moment *Mu*, which is a function of the axial force, the geometry of the section and masonry compression strength *fu.* A plastic hinge is then introduced in the section where *Mu* is attained (Magenes, 2000).
The ultimate moment is evaluated considering the masonry with zero tensile strength and assuming a nonlinear distribution of the compressions. In analogy with concrete, the nonlinear distribution can be substituted by a uniform distribution on a reduced area.

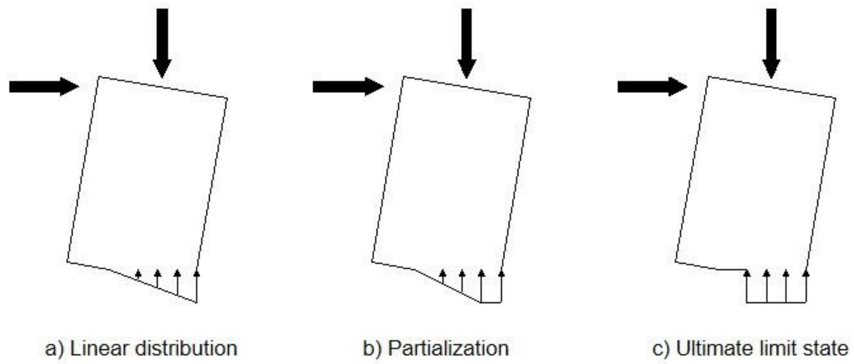


Figure 8.11
Distribution of compressive stresses in a masonry panel.

$$M_u = \left(\frac{L^2 \cdot t \cdot p}{2}\right) \cdot \left(1 - \frac{p}{k \cdot f_u}\right) \qquad (25)$$

With:

$$p = \frac{N_{Su}}{L \cdot t} \qquad (26)$$

That represents the average vertical compression on the section from the axial load P, f_u is the compressive ultimate strength and k is a coefficient that considers the distribution of the stresses in the compressed area and it is equal to 0,85.

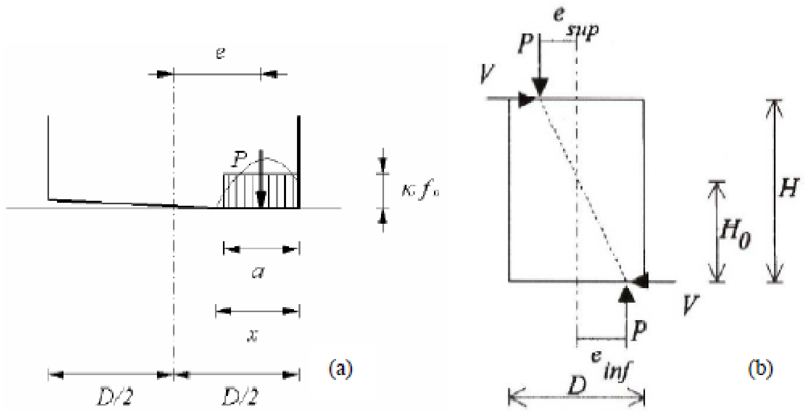


Figure 8.12
Simplified calculation of the flexural resistance of a masonry panel.

With a the lenght of the compressed area and N_{Su} the ultimate compressive stress and with N_{Ru} the maximum compressive strength of the wall:

$$\begin{cases} N_{Su} = p \cdot L \cdot t \\ N_{Ru} = k \cdot f_u \cdot a \cdot t \end{cases} \qquad (27)$$

And when $N_{Su} = N_{Ru}$ then $a = (p \cdot L)/(k \cdot fu\,)$

The eccentricity of the axial load at the ultimate state is:

$$e_u = \frac{L}{2}\left(1 - \frac{p}{k \cdot f_u}\right) \qquad (28)$$

And

$$V_u \cdot H_0 = M_u \qquad (29)$$

So

$$V_u = \frac{L \cdot t}{\alpha_v} \cdot \frac{p}{2} \cdot \left(1 - \frac{p}{k \cdot f_u}\right) \qquad (30)$$

$H_0 = H/2$

$\delta_u = 0{,}008H$

The shear behaviour of piers have been modelled as elastic-perfectly plastic, with the ultimate shear given by the relation (for brick masonry piers):

$V_u = Dt\tau_u$ with $\tau_u = \min(\tau_s; \tau_{ws}; \tau_b)$ (31)

Where τ_s is the shear stress corresponding to failure with sliding along bed joints (Magenes & Calvi, 1997), τ_{ws} and τ_b are the shear stresses related to failure with diagonal craking, due either to the head joint collapse or to the brick failure respectively (Mann & Muller, 1988).

Sliding along bed joints	$\tau_s = \frac{1.5c+\mu p}{1+3\frac{c\alpha_v}{p}}$ (32)
Diagonal cracking, head joints collapse	$\tau_{ws} = \frac{c+\mu p}{1+\alpha_v}$ (33)
Diagonal cracking, bricks collapse	$\tau_b = \frac{f_{bt}}{2.3(1+\alpha_v)}\sqrt{1+\frac{p}{f_{bt}}}$ (34)

Table 8.3
Shear stresses corresponding to piers shear failure mechanism.

For irregular masonry piers, where no regular brick pattern can be found, the ultimate shear of piers have been computed according to Turnsek and Sheppard (1980).
In the precedent equations c is the cohesion, μ the friction coefficient, p the average compressive stress, $\alpha_v = M/VN$ the shear coefficient, f_{bt} the brick tensile strength.
The shear collapse corresponds to the attainment of the ultimate drift $\delta_u = 0{,}4\%$ of the deformable height of the pier.

To summarize the behaviour of piers is influenced by the geometrical and mechanical properties of the elements, the vertical loads and the slenderness of the panels.

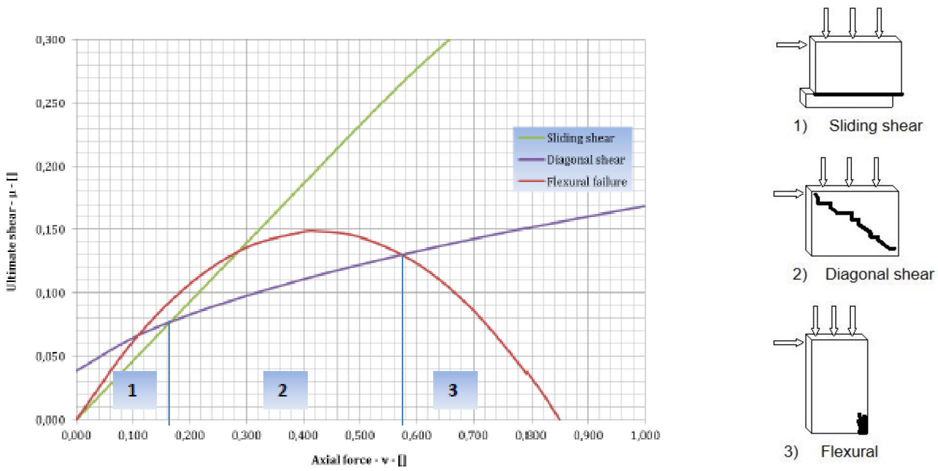


Figure 8.13
General description of piers behaviour in relation to the axial force.

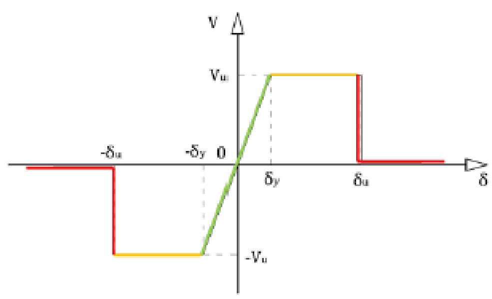


Figure 8.14
Force-displacement relationship for piers.

$$V_u = \min(V_{ds}; V_{ss}; V_f) \qquad (35)$$

$$\delta_y = \frac{V_u}{k} \qquad (36)$$

$k = \frac{1}{\frac{h^3}{12EI} + \frac{\chi h}{GA}}$ (37)

$\delta_u = (0{,}004 \div 0{,}008)h$ (38)

Spandrels are elements located over the openings, with horizontal axes connected to the piers of the same wall.

They are particularly important because they couple adjacent piers influencing the overall behaviour of a building.

Also these elements present a central deformable part, equal to the openings width, suffering of low vertical and horizontal compressions.

For seismic loads the solicitation is principally shear type.

Flexural failure occurs in one of the extremities of the deformable part when there are value of flexural moment:

$V_{max} \cdot H_0 = P \cdot e' = M_u = \frac{p \cdot D^2 \cdot t}{2} \cdot \left(1 - \frac{p}{k \cdot f_u}\right)$ (39)

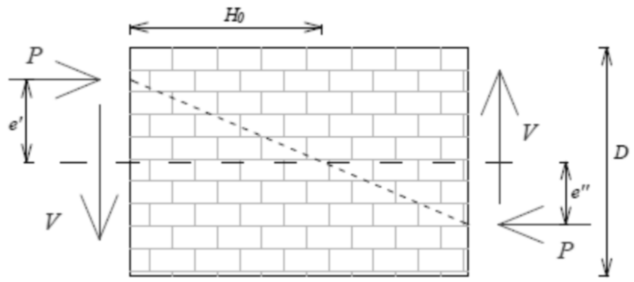


Figure 8.15
Masonry spandrel.

So

$V_u = \left(\frac{D^2 \cdot t}{H_0} \cdot \frac{p}{2}\right) \cdot \left(1 - \frac{p}{k \cdot f_u}\right) = \left(\frac{D \cdot t}{\alpha_v} \cdot \frac{p}{2}\right) \cdot \left(1 - \frac{p}{k \cdot f_u}\right)$ (40)

While the shear failure occurs when:

$V_u = 0{,}9 \cdot D \cdot t \cdot \frac{c + \mu \cdot p}{1 + \alpha_v}$ (41)

Where $\mu \cdot p$ is close to zero, so the resistance depends principally on the cohesion in the section of intersection between spandrels and pears.

The spandrel element is formulated similarly to the pier element, taking into account the different orientation of bed joints with respect to the axial force.

The building modelled for this example has a plan of 10x40 meters and four floors 3 meters high. The “frame model” used to describe the masonry structure is the SAM method by Magenes and Calvi (1996), then implemented by Magenes and Della Fontana (1998). The method proposes the description of the walls through linear elements: in the finite element program, axial columns represent piers while beams represent spandrels. A rigid portion individuates the physical intersection between piers and spandrels.

In SAP2000 shear hinges are located considering the minimum value between the three representative collapse modes respectively for piers – combined compressive and bending and overturning failure, diagonal shear failure, sliding shear failure – and for spandrels – combined compressive and bending failure and shear failure.

Also in the case of a simple masonry structure, the application of the “exoskeleton” gave promising results. The solicitation applied required the location of SMADs in only one direction, where the lateral displacements needed to be limited with insignificant influence on the other principal direction.
Again, an initial pretension on the dissipative wires increases the efficiency of the system.

$$\gamma_m = 2$$
$$E_m = 1000 \cdot f_k = 6420\ N/mm^2$$
$$G_m = 0{,}4 \cdot E_m = 2568\ N/mm^2$$

Parameter	Value
H (cm)	300
L1 (cm)	200
L2 (cm)	300
t (cm)	30
H1 (cm)	150
H2 (cm)	200
A1 (cm2)	600
A2 (cm2)	900
k1(kN/m2)	18699
k2 (kN/m2)	12466
α_{v1}	0,5
α_{v2}	0,75

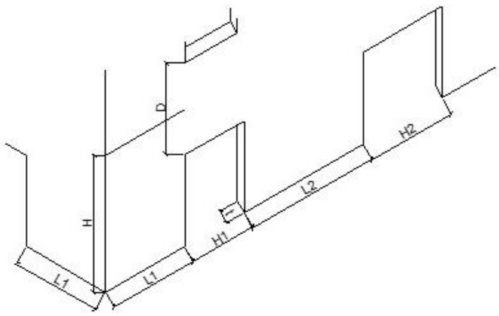


Table 8.4
Geometrical features of the equivalent frame and definition of the mechanical properties.

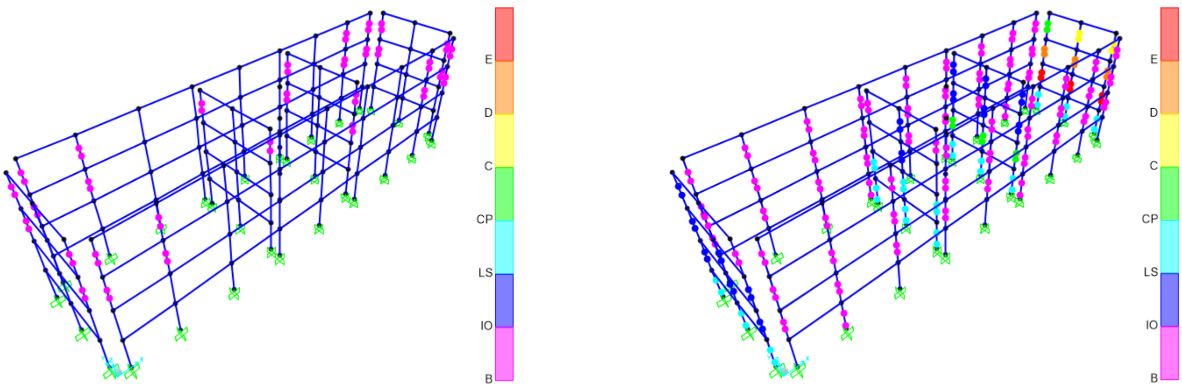


Figure 8.16
Pushover analysis (Y+ mode) on an existing building located in zone 3. On the left step 0, on the right last step.

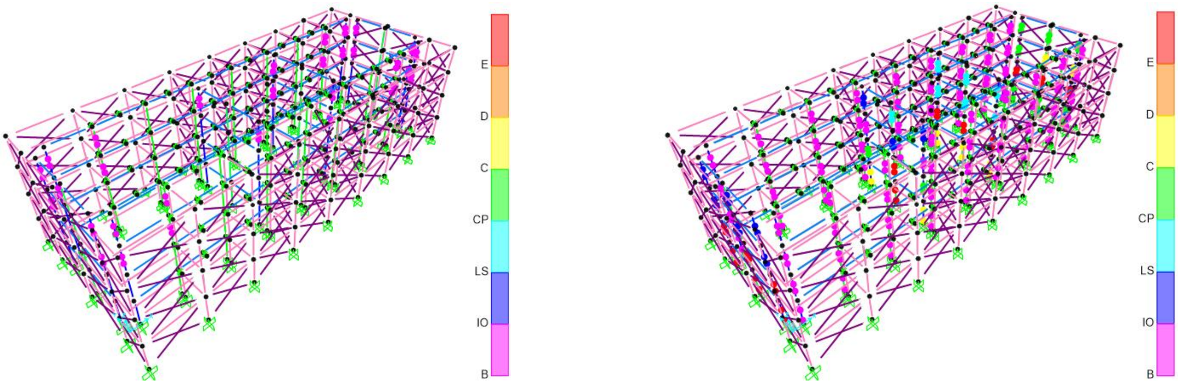
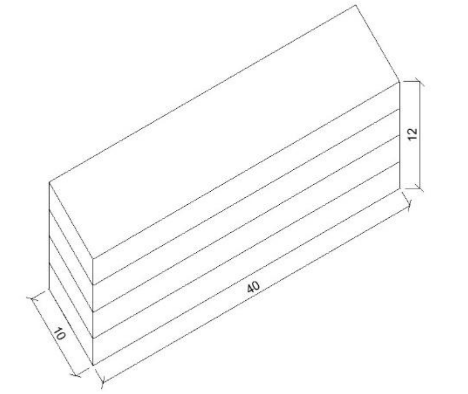
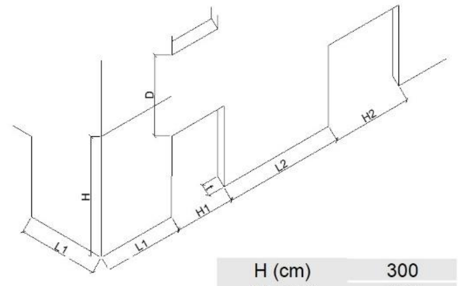


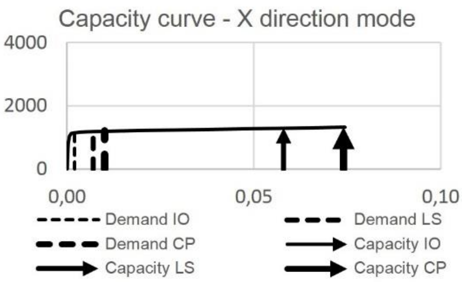
Figure 8.17
Pushover analysis (Y+ mode) on an existing building located in zone 3 with the “adaptive exoskeleton”, SMAD type 05_10. On the left step 0, on the right last step.

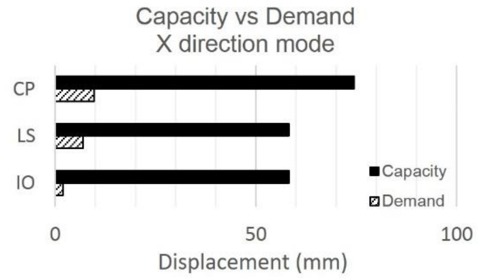


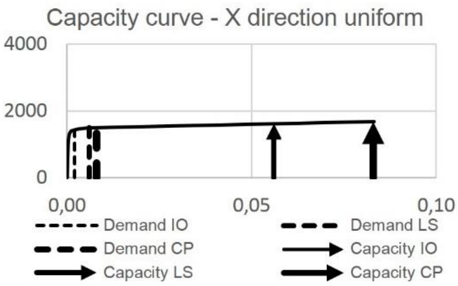


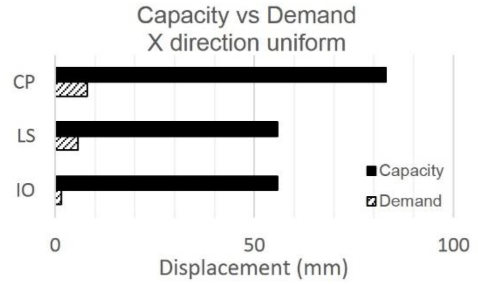
t (cm)	30
D (cm)	200

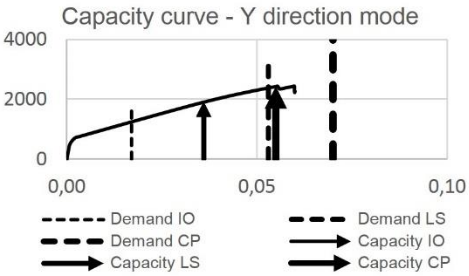
H (cm)	300
H1 (cm)	150
H2 (cm)	200
L1 (cm)	200
L2 (cm)	300

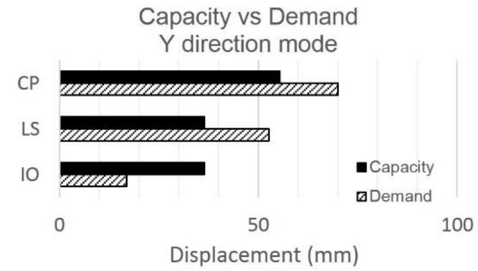


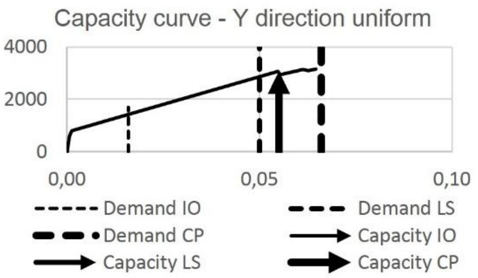


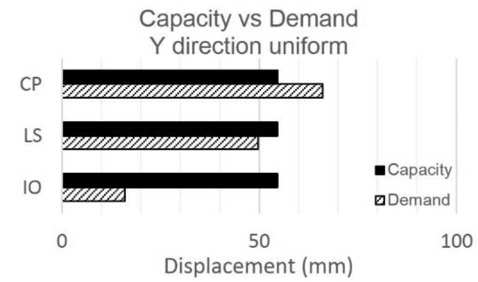


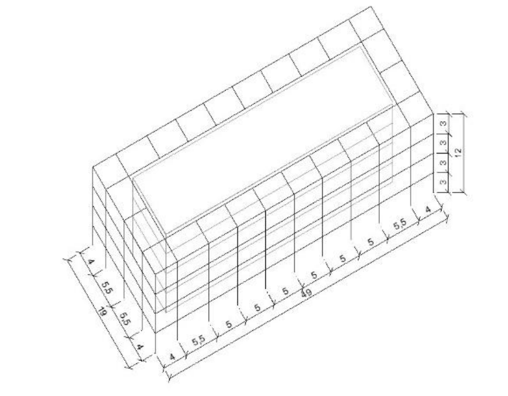


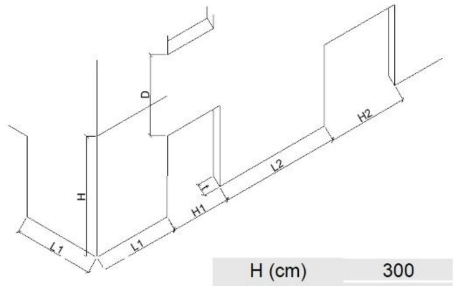






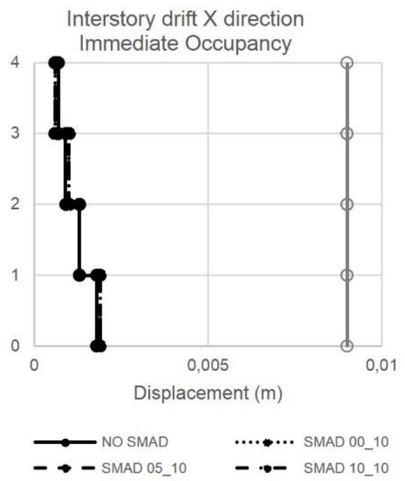


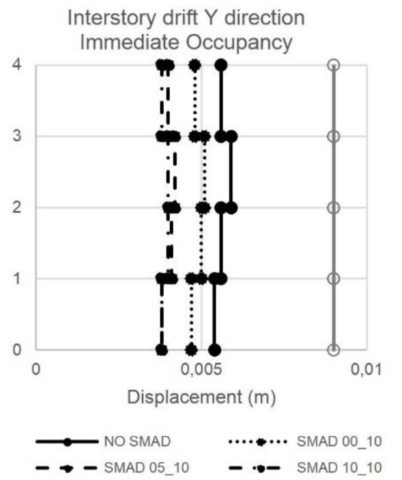


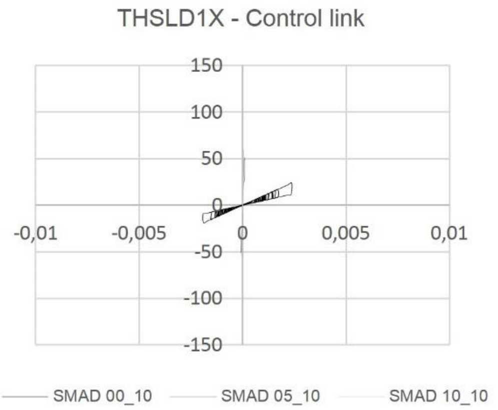


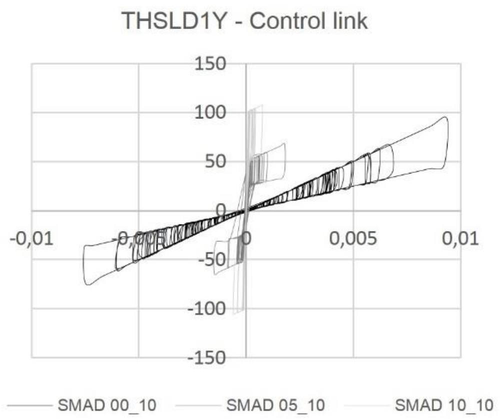
t (cm)	30
D (cm)	200

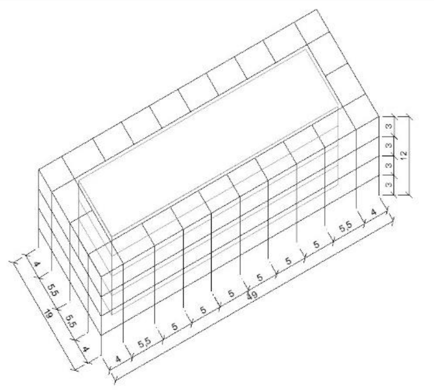
H (cm)	300
H1 (cm)	150
H2 (cm)	200
L1 (cm)	200
L2 (cm)	300

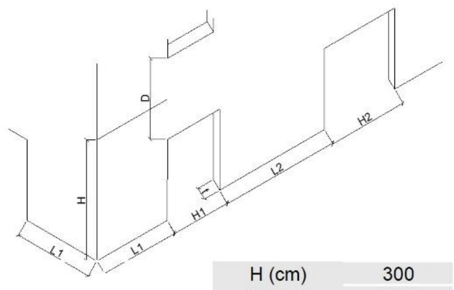






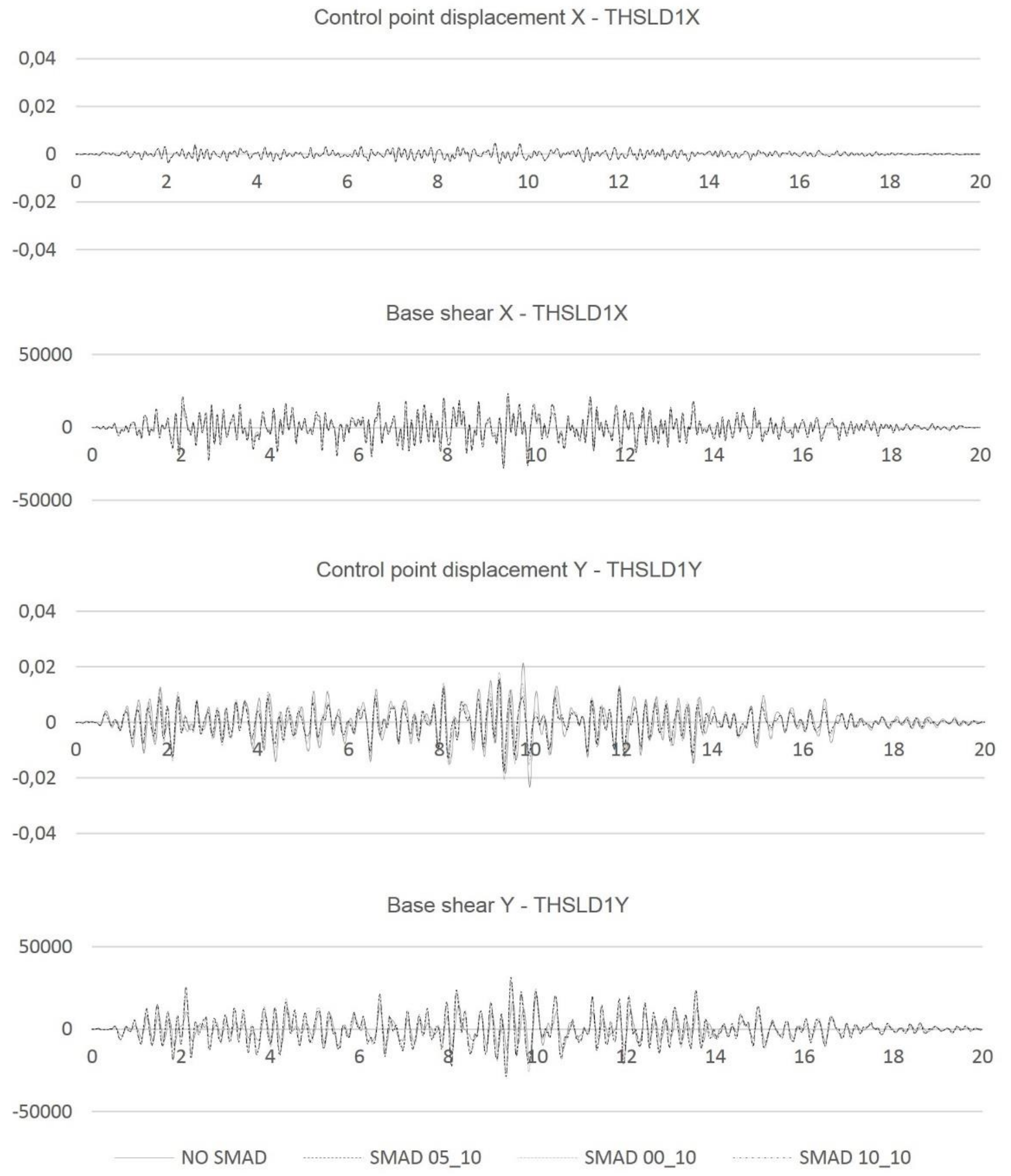


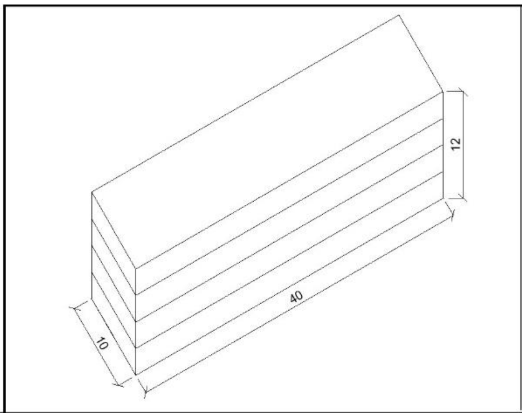


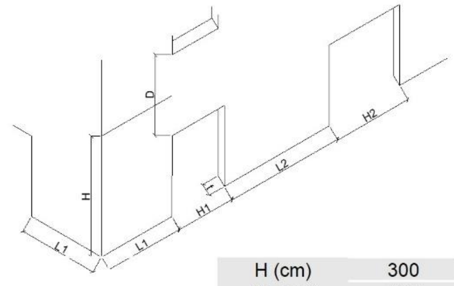


t (cm)	30
D (cm)	200

H (cm)	300
H1 (cm)	150
H2 (cm)	200
L1 (cm)	200
L2 (cm)	300

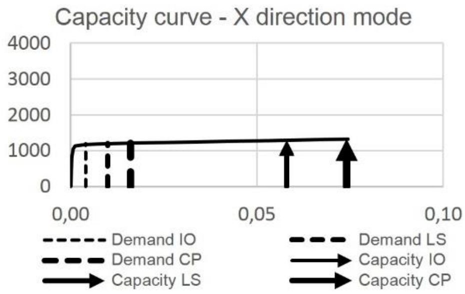


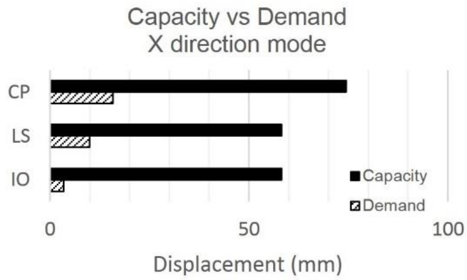


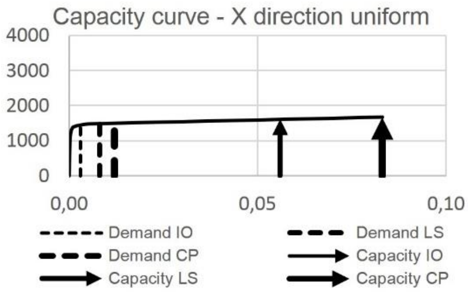


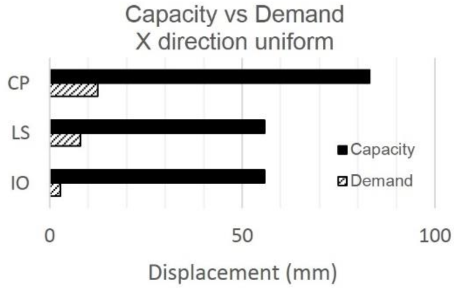
t (cm)	30
D (cm)	200

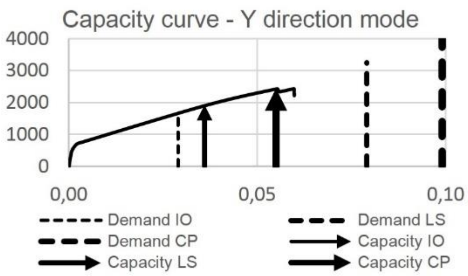
H (cm)	300
H1 (cm)	150
H2 (cm)	200
L1 (cm)	200
L2 (cm)	300

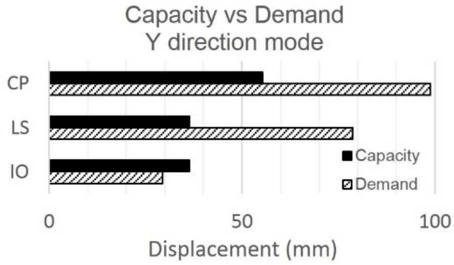


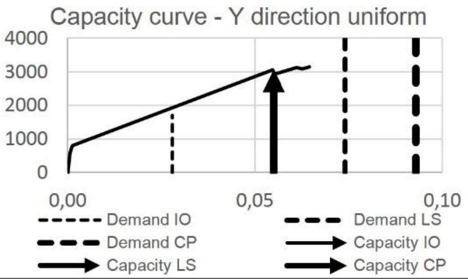


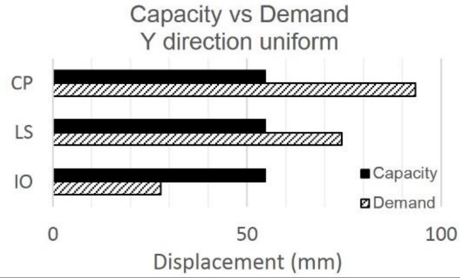


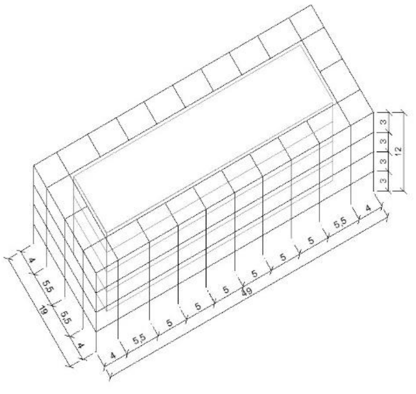


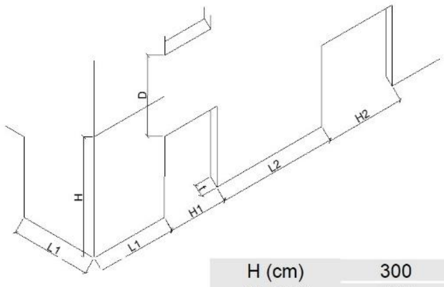






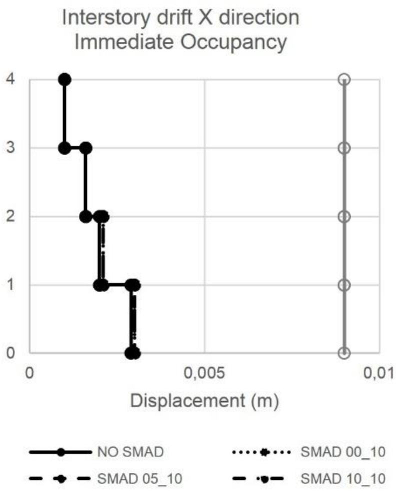


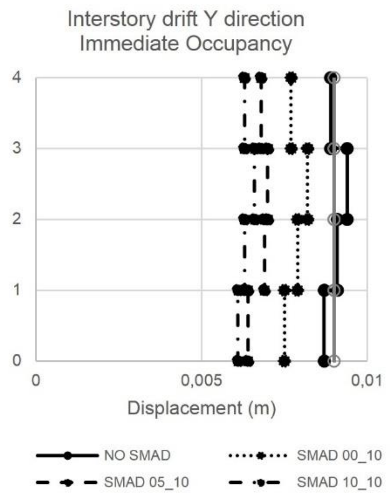


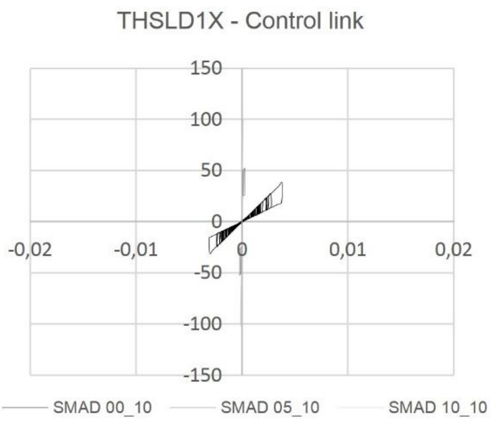


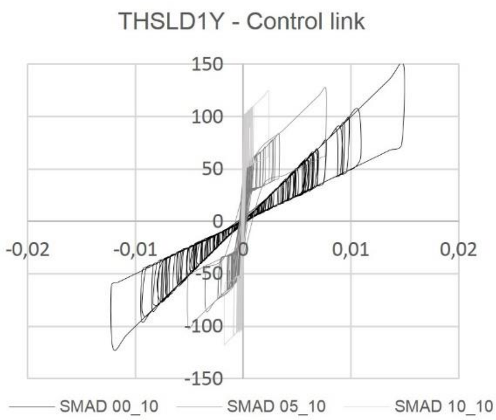
t (cm)	30
D (cm)	200

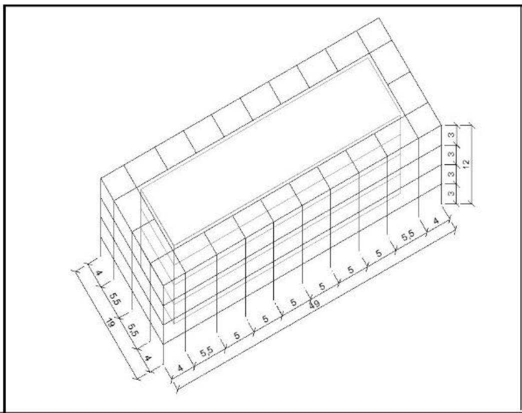
H (cm)	300
H1 (cm)	150
H2 (cm)	200
L1 (cm)	200
L2 (cm)	300

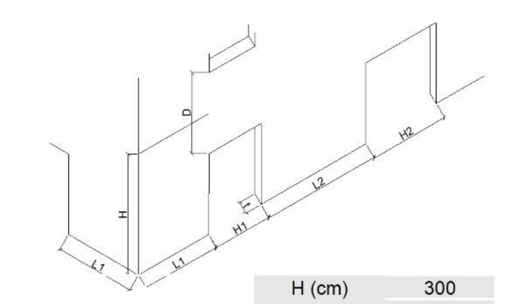






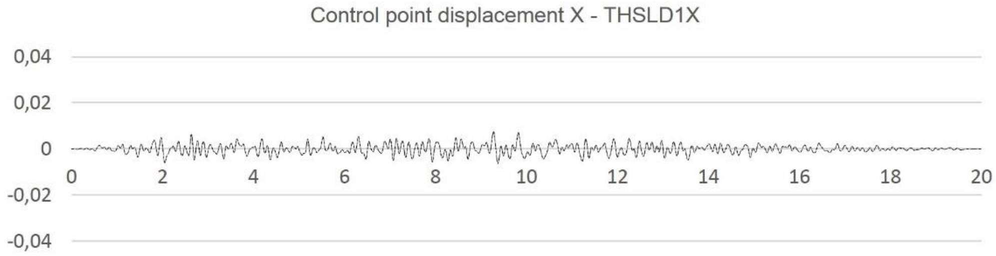


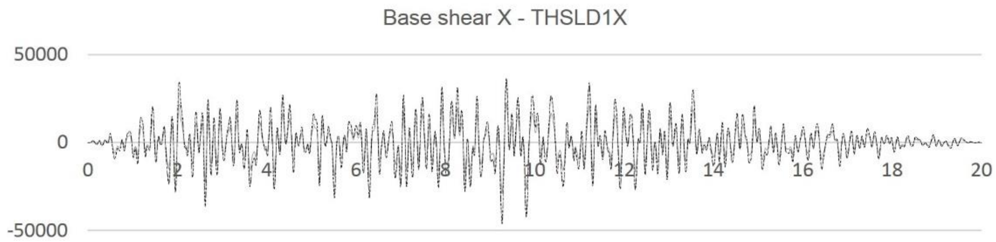


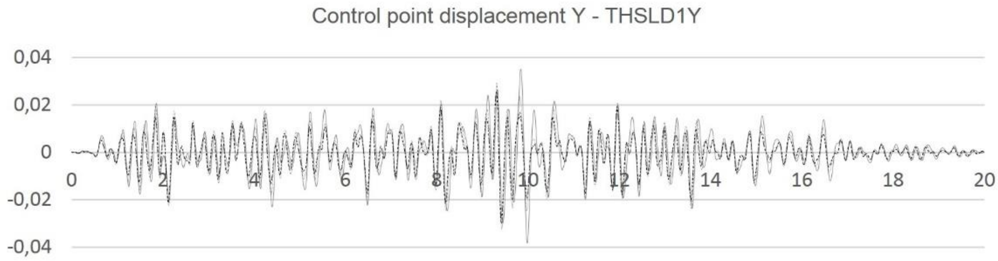


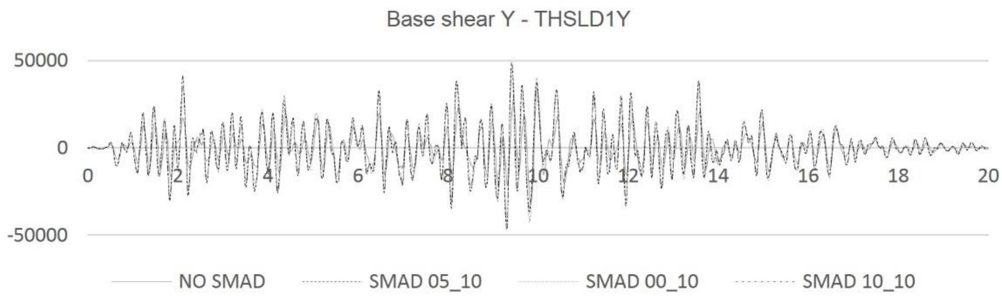
t (cm)	30
D (cm)	200

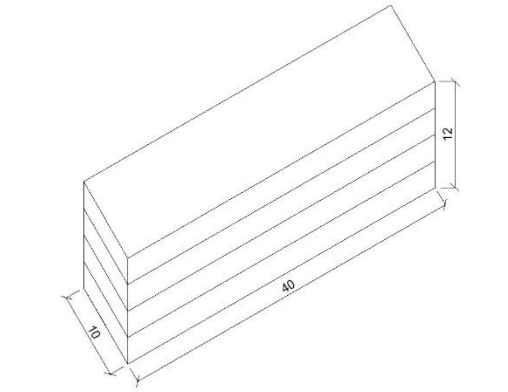
H (cm)	300
H1 (cm)	150
H2 (cm)	200
L1 (cm)	200
L2 (cm)	300

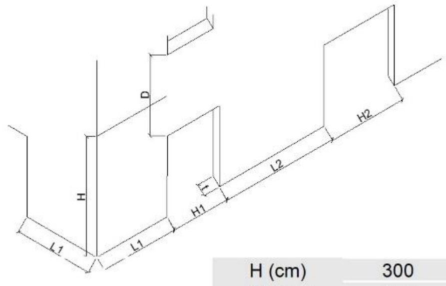






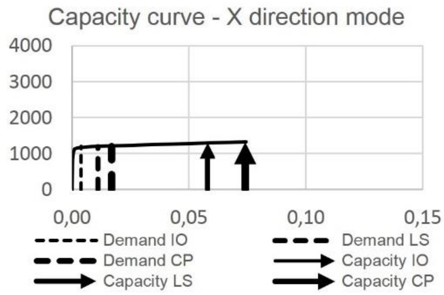


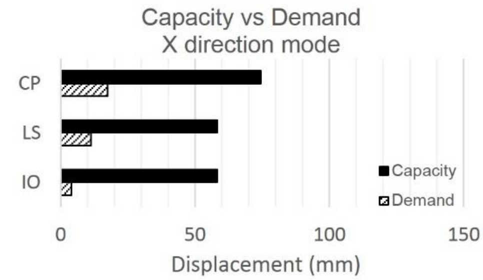


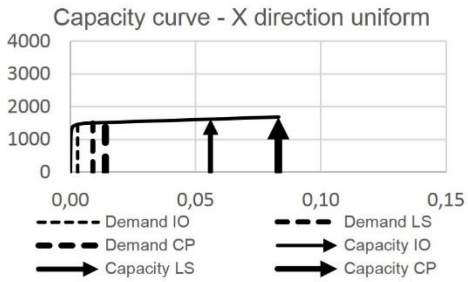


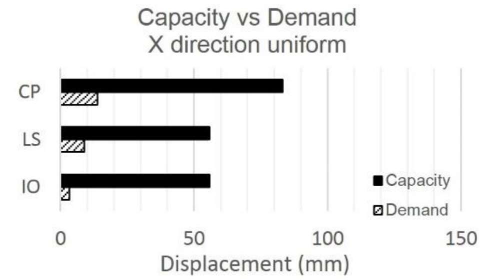
t (cm)	30
D (cm)	200

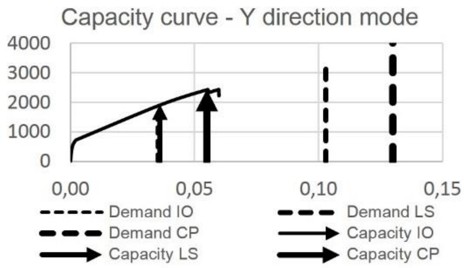
H (cm)	300
H1 (cm)	150
H2 (cm)	200
L1 (cm)	200
L2 (cm)	300

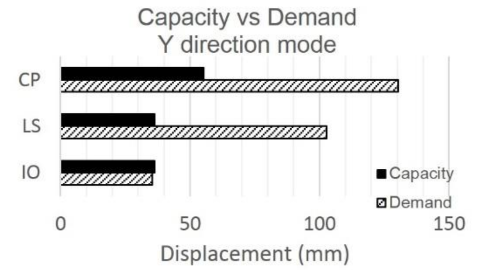


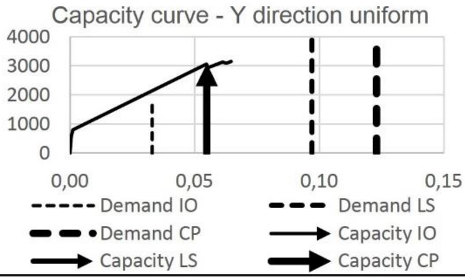


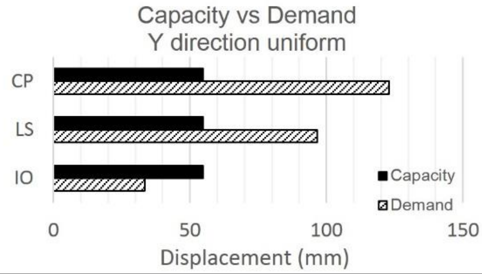


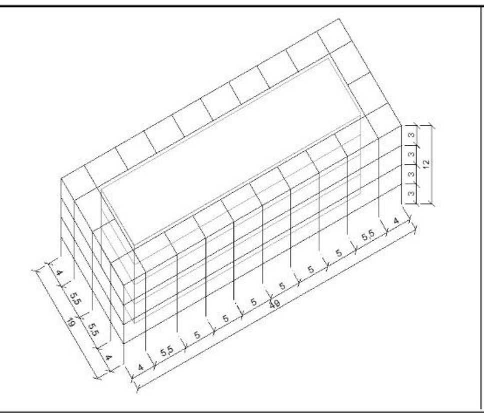


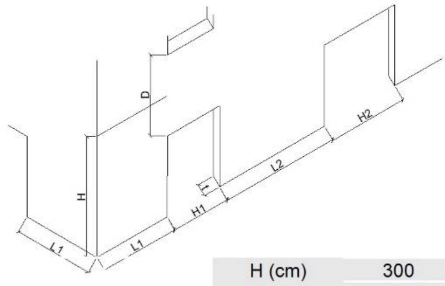






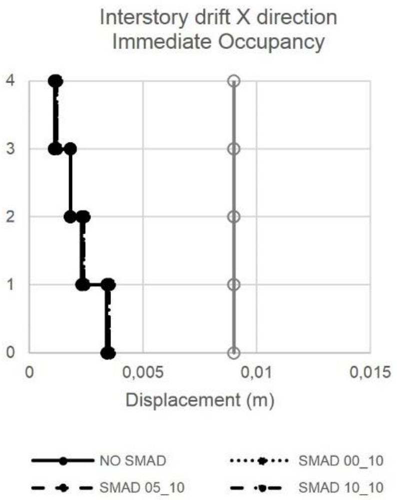


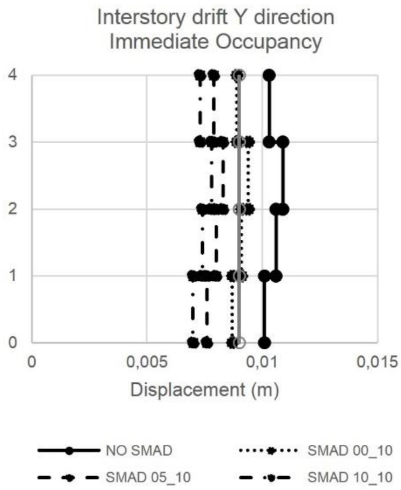


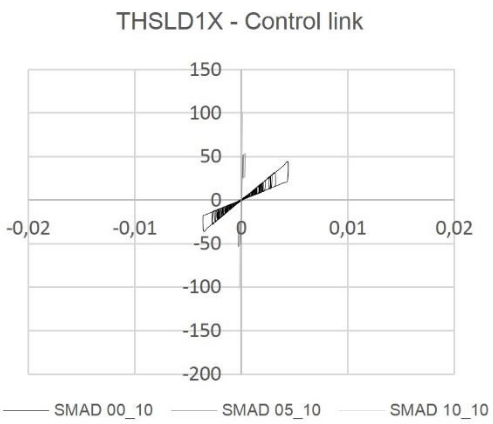


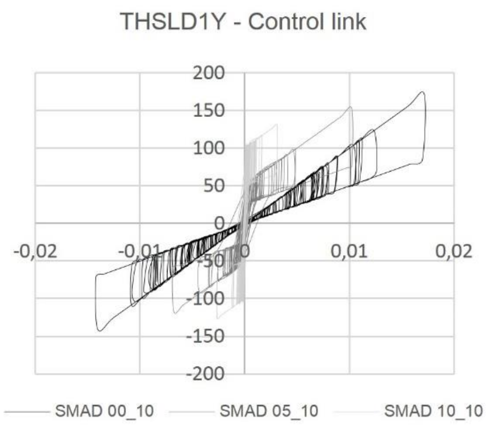
t (cm)	30
D (cm)	200

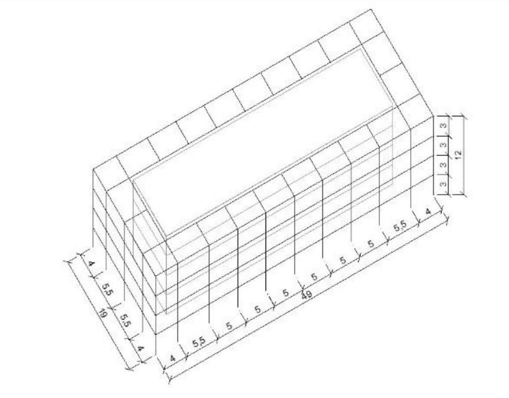
H (cm)	300
H1 (cm)	150
H2 (cm)	200
L1 (cm)	200
L2 (cm)	300

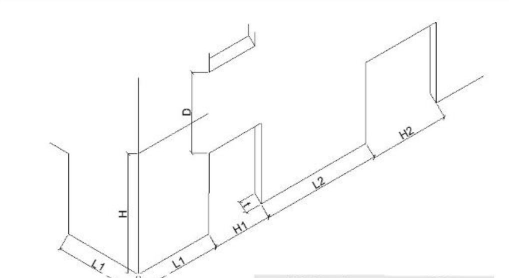






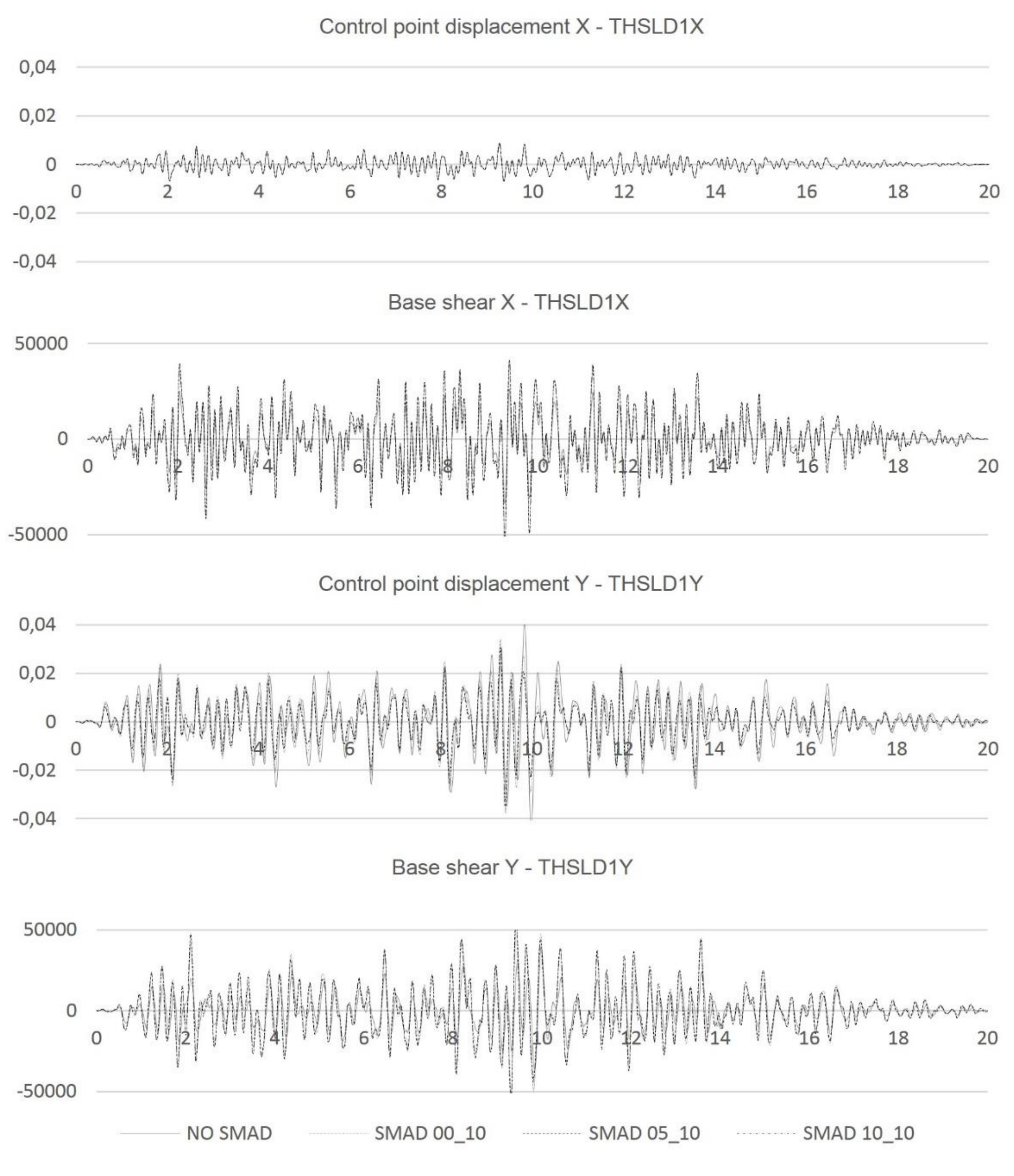






t (cm)	30
D (cm)	200

H (cm)	300
H1 (cm)	150
H2 (cm)	200
L1 (cm)	200
L2 (cm)	300



8.4 Real case study

In the 1957 the Institute IACP of Brescia undertakes the construction of affordable dwellings for refugees in the district of San Bartolomeo, in the northern part of the city.
The area, which at the time of construction was located in the urban periphery, is today in a central position, nearby services of considerable importance, such as the University of Brescia and the Civil Hospital, and important traffic networks.
The area is now part of the North District of Brescia and it is included in an area of low seismic hazard, with the possibility of moderate quakes.
The final project dates 13 November 1954 and it is signed by the architect Angelo Boccanera, at that time director of the IACP of Brescia.
The total surface of the area is 16.000 sq.m and it comprises, houses, streets, playing fields and green areas.
The dwellings are shared by thirteen buildings, of which five are with four storeys, six with three storeys and two with two storey, for a total of two-hundreds dwellings.
The prospect of the different types of buildings report the characteristics shown in Table 8.5.

Units	Buildings	Dwellings	Dimensions	Types of dwellings for number of rooms		
				3	4	5
A1, A2, A3, A4, A5	5	120	25.087 m^3	120	-	-
B1	1	17	4.247 m^3	15	1	1
B2, B3	2	36	8.494 m^3	36	-	-
C1, C3	2	12	3. 709 m^3	-	12	-
C2	1	7	1.854 m^3	3	4	-
D1, D2	2	8	1.847 m^3	8	-	-
TOTAL	13	200	45.283 m^3	182	17	1

Table 8.5
Characteristics of the buildings.

In this research, the blocks belonging to the category A have been considered.
The structure is an irregular concrete, both vertically and horizontally, with masonry infill. The buildings perform for static loads, but they are not designed to resist to seismic loads. Together with the structural issue, there consistent architectural and functional problems.
The concrete frame presents brick infill of "Trieste" type along the perimeter and around the staircase. The building, almost symmetrical in both directions, is characterized by a rectangular plan with dimensions of about 10 meters for 40 meters and four floors 3,1 meters high over a ground floor 1 meter high for a total elevation of 13,4 meters.
In order to take into account the uncertainties involved in the assessment of the existing structure, the Italian structural code, in accordance with the Eurocode, has introduced two important concepts: the knowledge levels (LC in Italian) and the confident factors (CF). Three different levels of knowledge are defined:

- LC1: limited knowledge;
- LC2: intermediate knowledge;
- LC3: high knowledge.

The level is assigned according to the available information on geometry, details, materials. According to the assigned level of knowledge, the mechanical properties are reduced by means of an additional partial factor, the so called confidence factor (CF). In the considered case it has been assumed an intermediate level of knowledge (LC2), so the corresponding CF is 1.2.

Figure 8.18
A building type A in the district of San Bartolomeo. © M. Bertoni, M. Bettini, R. Prandelli corso e Laboratorio di Architettura e Composizione 2 (Unibs).

The model of the panels in the software SAP2000 is realized with the “strut model” with the same consideration discussed in one of the previous paragraph.
Pushover analysis underlined the necessity of an intervention that was realized verifying three types of SMADs, namely 0, 5 and 10 mm of precompression.
The time history analyses verified an interstory drift under the limits imposed by the regulation but, within this example, the considerations of Morandi et al. (2011) were exploited to achieve a clearer interpretation of the in-plane behaviour of the single panels, with the introduction of different performance limits and their relative definitions:
- Operational level is verified when no panel reaches an interstory drift of 0,2%;
- Immediate occupancy level is verified when no panel reaches an interstory drift of 0,3%;

- Life safety level is verified when no panel reaches an interstory drift of 1%.

To evaluate the necessity of the procedure the limits were at first verified for the interstory drifts of the control points, coincident with the centre of masses of each floor. In figure 8.19 the behaviour of the single panels before and after the intervention with the three typologies of SMADs are evaluated: the 5mm and 10mm pre-compressed SMADs allow to achieve the satisfaction of the three performance levels defined by Morandi et al. (2011).

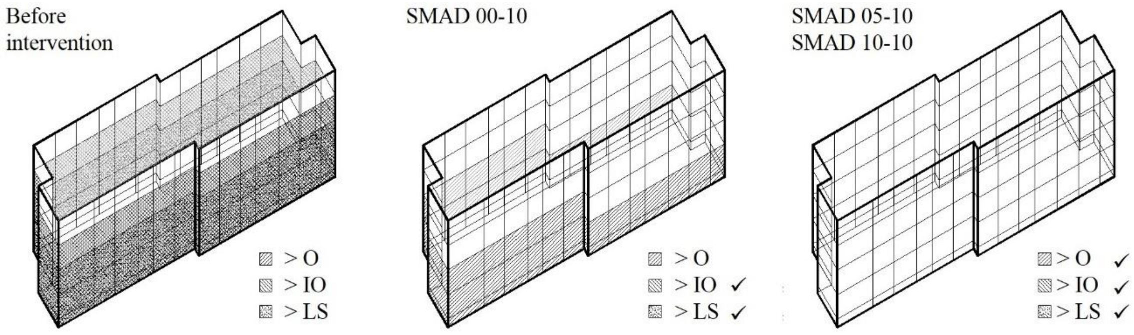


Figure 8.19

Behaviour of the infill panels before and after the application of the "adaptive exoskeleton".

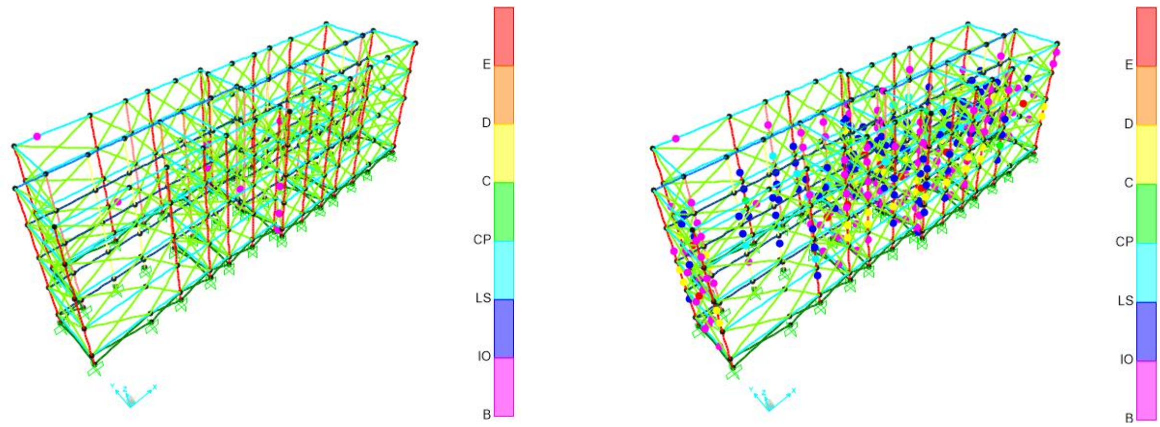


Figure 8.20
Pushover analysis (Y+ mode) applied on the selected building. On the left step 0, on the right last step.

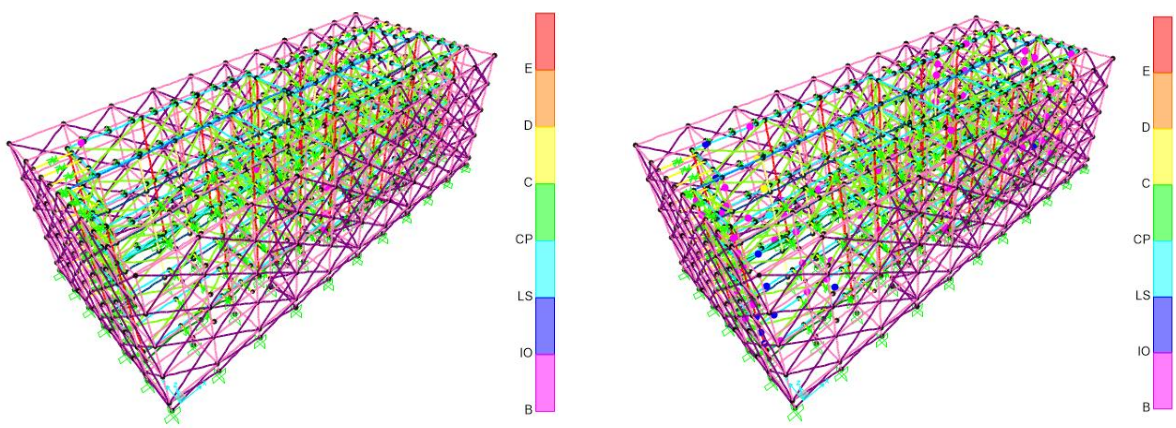
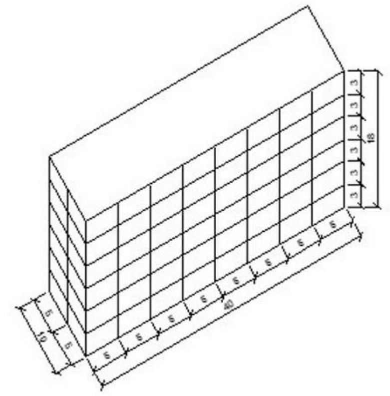
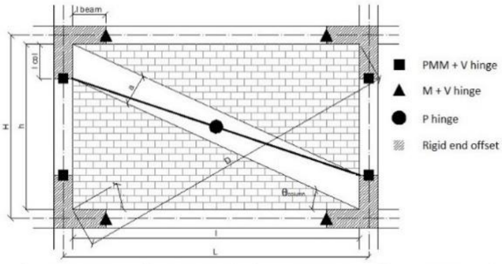
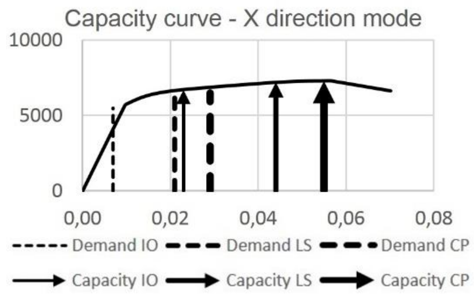


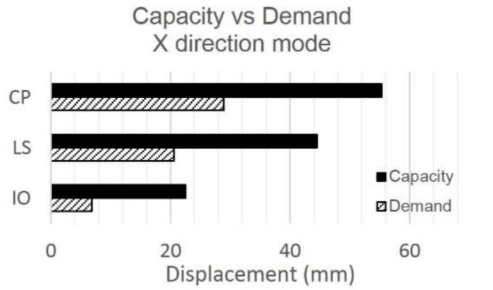
Figure 8.21
Pushover analysis (Y+ mode) applied on the selected building. with the "adaptive exoskeleton", SMAD type 05_10. On the left step 0, on the right last step.

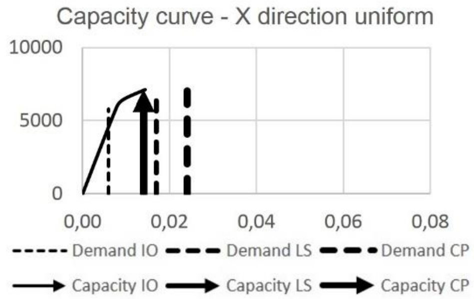


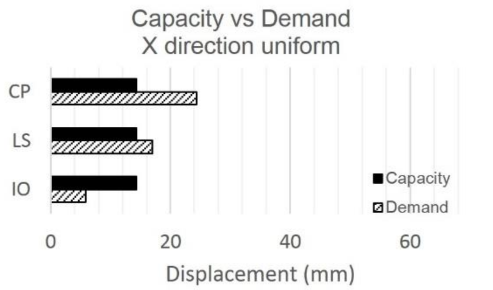


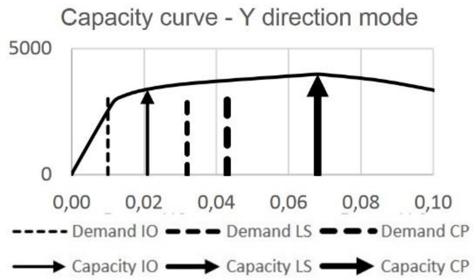
H (cm)	300	a (cm)	49
h (cm)	270	l col (cm)	54,01
l (cm)	460	θ col (rad)	0,439
t (cm)	40	l beam (cm)	49,02
D (cm)	533	θ beam (rad)	1,496

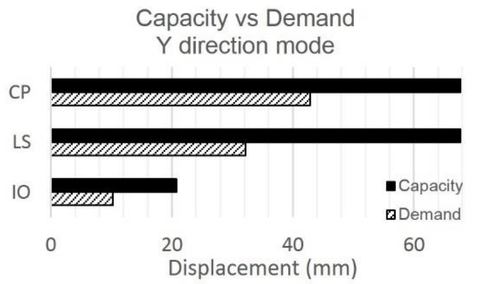


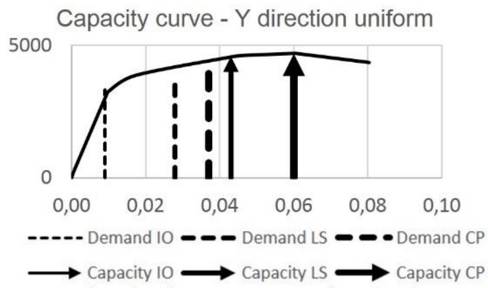


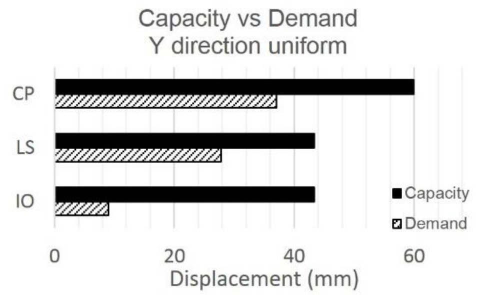






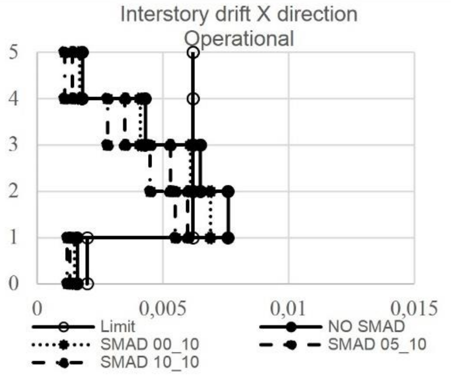


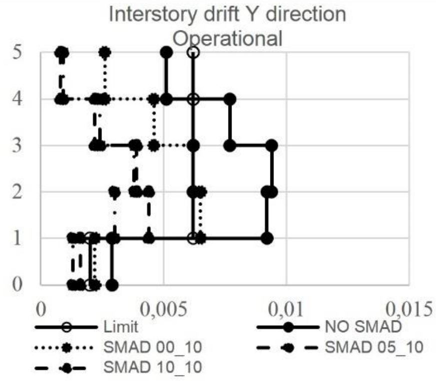


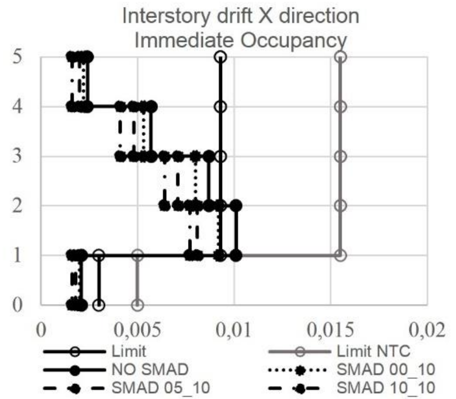


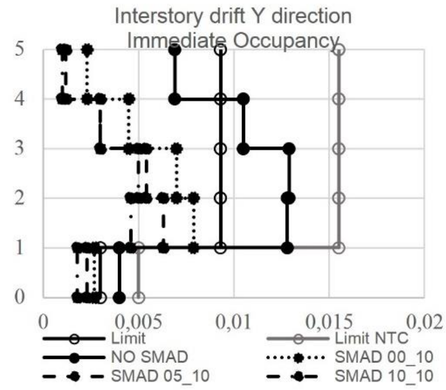

PROSPETTO SUD-EST
PROSPETTO NORD-EST
PIANTA PIANO TIPO

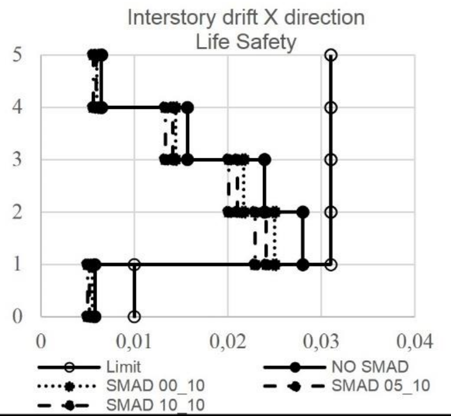

4
2
V
CM
Z1

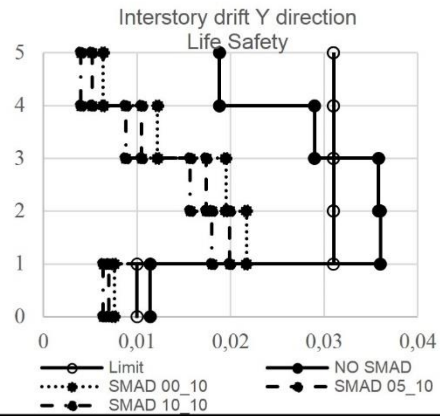

Interstory drift X direction
Operational
Limit
NO SMAD
SMAD 00_10
SMAD 05_10
SMAD 10_10

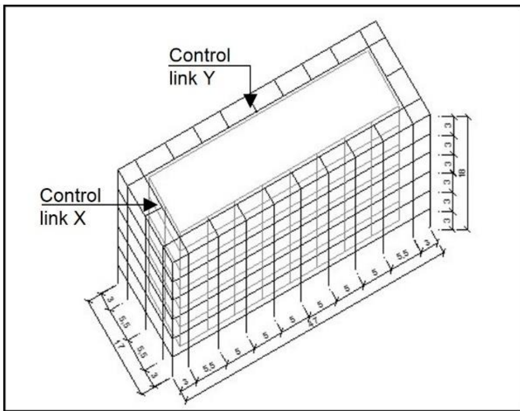

Interstory drift Y direction
Operational
Limit
NO SMAD
SMAD 00_10
SMAD 05_10
SMAD 10_10

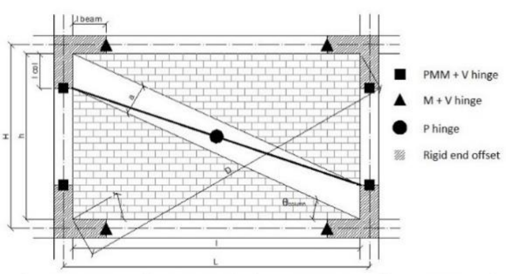

Interstory drift X direction
Immediate Occupancy
Limit
Limit NTC
NO SMAD
SMAD 00_10
SMAD 05_10
SMAD 10_10


Interstory drift Y direction
Immediate Occupancy
Limit
Limit NTC
NO SMAD
SMAD 00_10
SMAD 05_10
SMAD 10_10

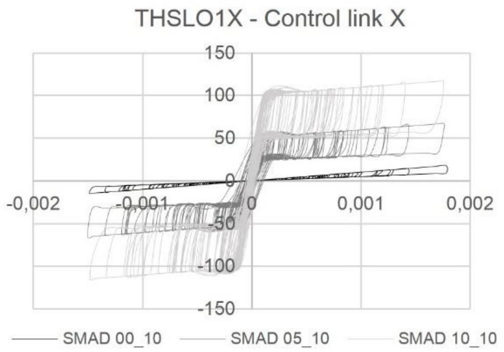

Interstory drift X direction
Life Safety
Limit
NO SMAD
SMAD 00_10
SMAD 05_10
SMAD 10_10

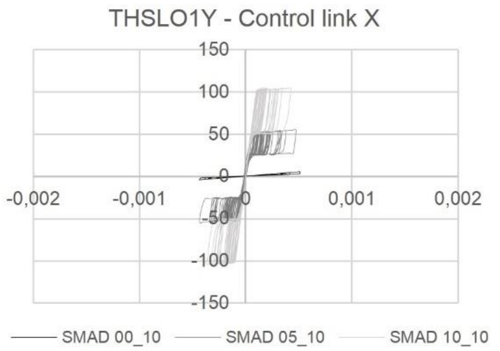

Interstory drift Y direction
Life Safety
Limit
NO SMAD
SMAD 00_10
SMAD 05_10
SMAD 10_10

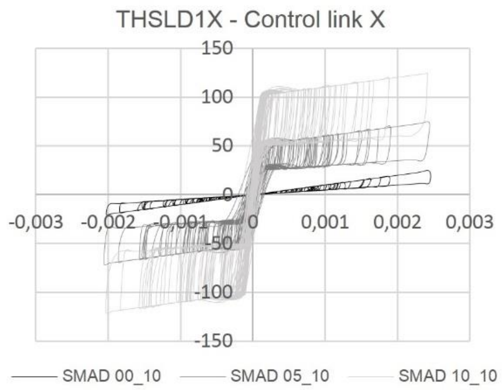


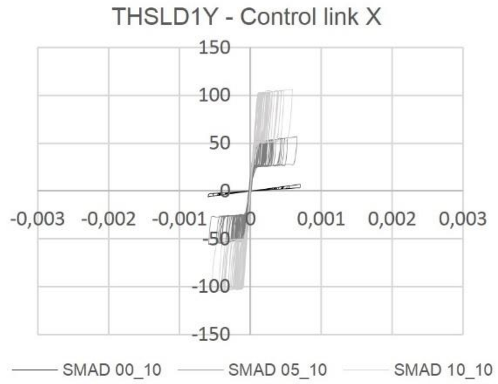


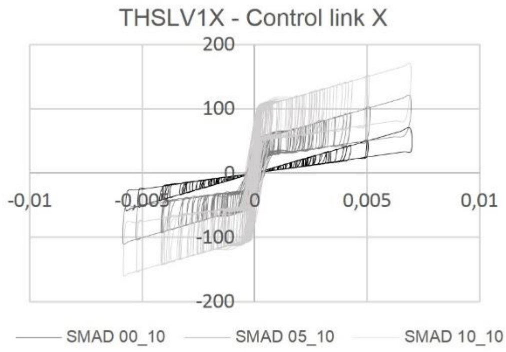
H (cm)	300	a (cm)	49
h (cm)	270	l col (cm)	54,01
l (cm)	460	θ col (rad)	0,439
t (cm)	40	l beam (cm)	49,02
D (cm)	533	θ beam (rad)	1,496

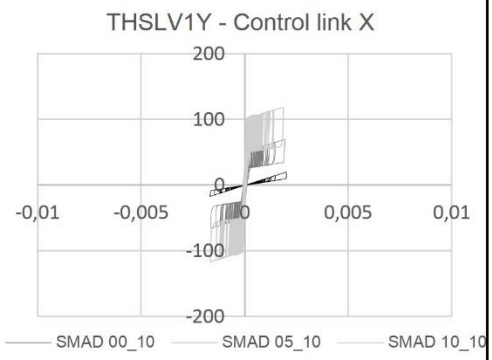


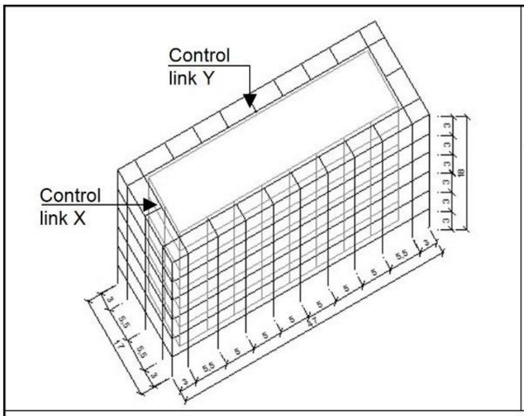


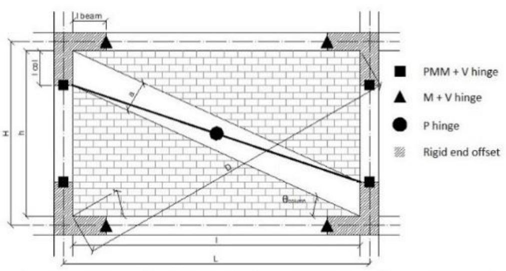




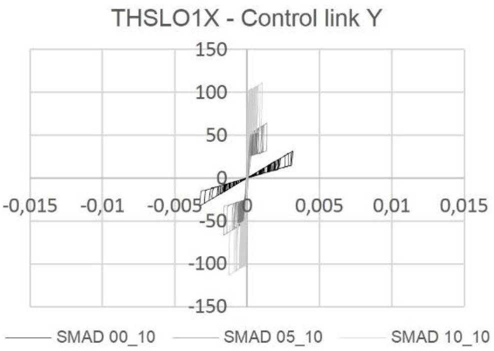


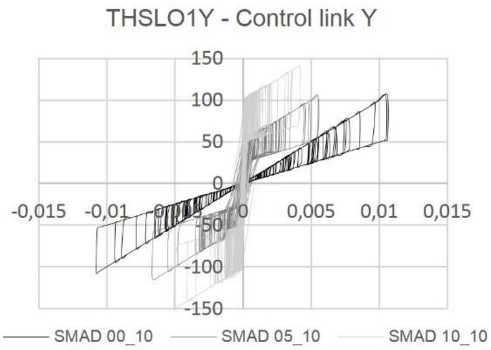


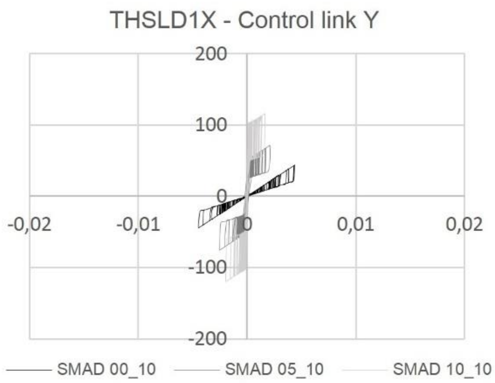


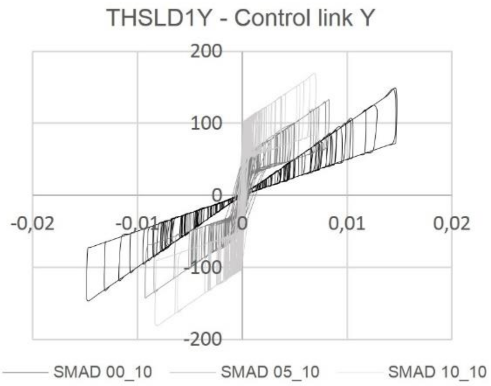


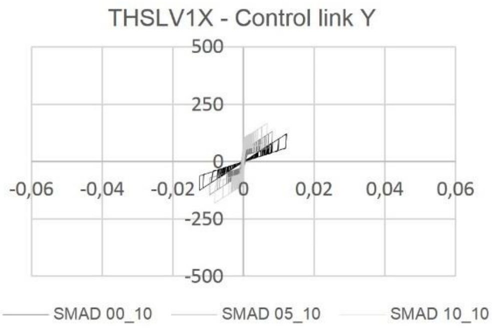
H (cm)	300	a (cm)	49
h (cm)	270	l col (cm)	54,01
l (cm)	460	θ col (rad)	0,439
t (cm)	40	l beam (cm)	49,02
D (cm)	533	θ beam (rad)	1,496

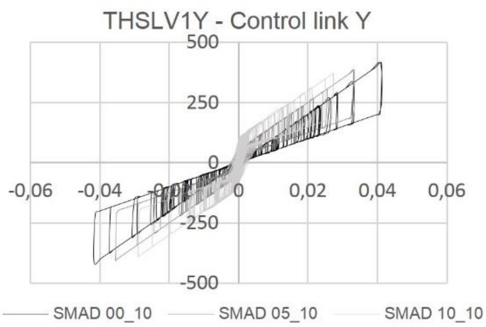


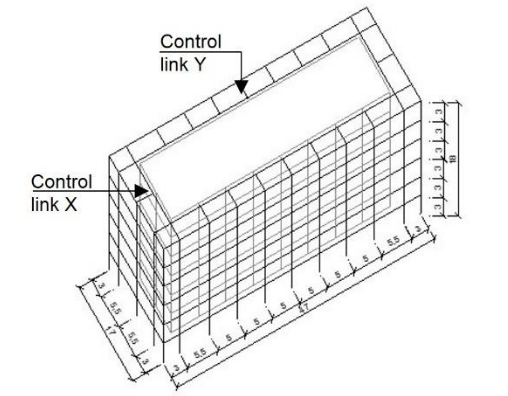


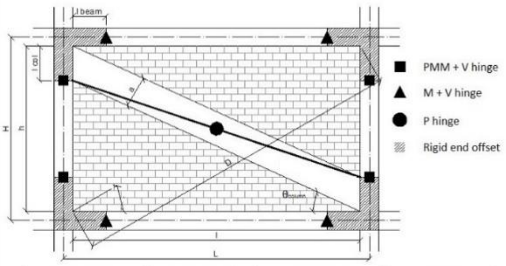




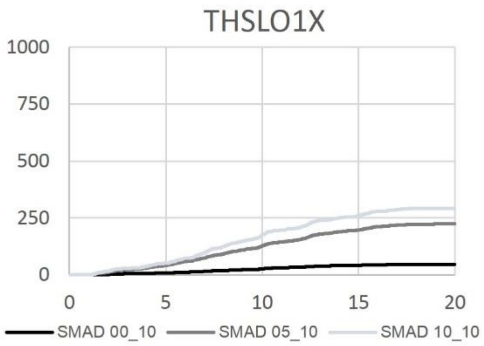


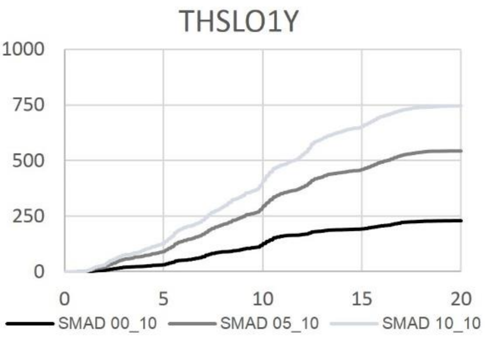


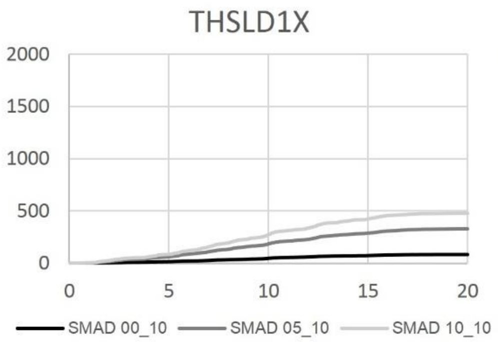


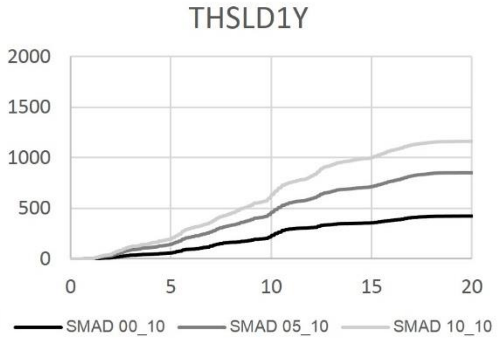


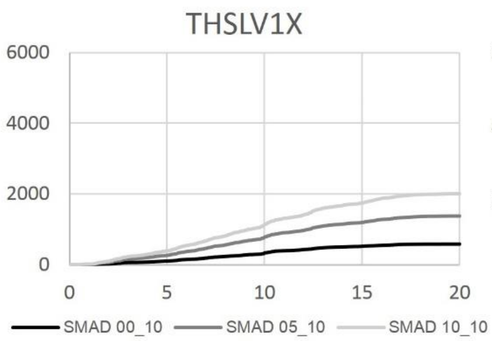
H (cm)	300	a (cm)	49
h (cm)	270	l col (cm)	54,01
l (cm)	460	θ col (rad)	0,439
t (cm)	40	l beam (cm)	49,02
D (cm)	533	θ beam (rad)	1,496

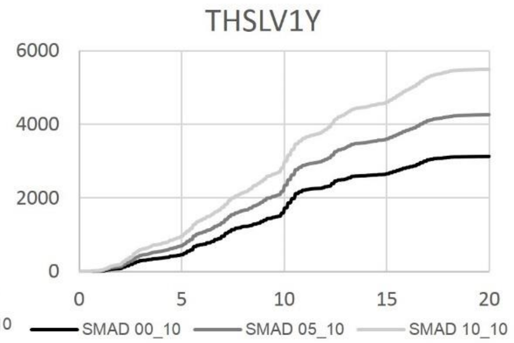












8.5 Discussion

The “adaptive exoskeleton” strategy can be seen as a part of a general plan of urban requalification. Every application impacts not only on the building scale but also on the urban and neighbourhood dimensions, activating new visual realities and also new ways to experience the space and the environment.
The steel frame composing the “exoskeleton” can be designed as a filter space between the public and private domain, for instance allocating common social services in the lower storey.
The technique allows also roof extensions, whose sale revenues might partially cover the upgrade costs.
Depending on urban planning restrictions, the structure can be designed in adhesion to the existing building, or can become three-dimensional providing the space to allocate new functions, such as balconies, greenhouses, winter gardens, etc.
A fundamental consideration is about the applicability of the strategy, which substantially requires free fronts to be applied. Isolated buildings are the most suited for the application, but also row buildings can be equipped with a “partial exoskeletons”, acting only in one direction that is usually the one more subjected to uncontrolled lateral displacements.
However, if we look at the Italian situation presented in figure 8.22, we see that most of the residential constructions in the different period were built with no adjacent sides to other buildings or with only one side of contiguity. Of these, the greater share is constituted by buildings dated after the Second World War and this increases the margin of operability of the strategy.

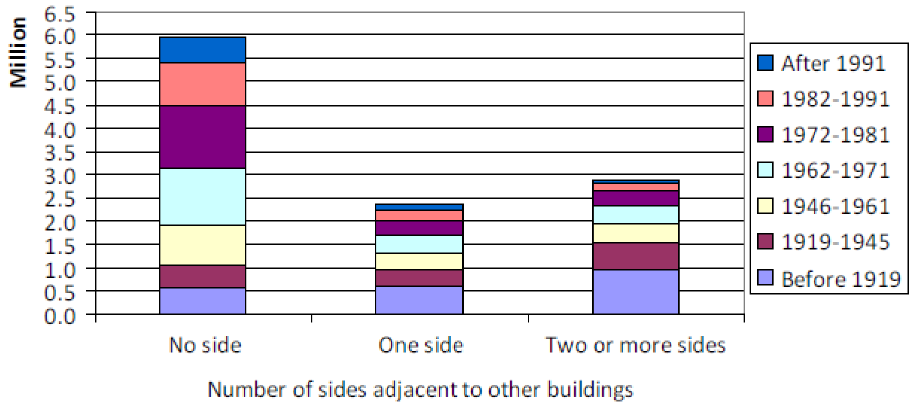


Figure 8.22
Number of Italian residential buildings by contiguity to other buildings and construction period in Italy (Source: ISTAT, report 2004).

9. THE ADAPTIVE EXOSKELETON - DISCUSSION

9.1 Introduction

Obsolescent and degraded buildings can effect negatively the image of a neighbourhood, decreasing the property values, taxes, services, discouraging future investments.
When conditions of damage increases dramatically, the owners start be unable to maintain their real estate and the dwellers start to be unsatisfied of their living standards, deciding progressively to leave or becoming accustomed to the situation. In turn, more properties are abandoned or suffer of major damages.
This imposes high social costs upon the local authorities, attracting crime (Schilling, 2002) and spreading the detrimental effects in the surrounding communities.
This mechanism can be described using the “Broken Window Theory” (Wilson & Kelling, 1989), a criminological theory of the norm-setting, signalling effect of urban disorder on anti-social behaviour. The theory states that maintaining and monitoring urban environments to prevent small crimes, results in preventing more serious crimes, such as if a “broken window is left unrepaired, all the rest of the windows will soon be broken.” (Wilson & Kelling, 1989).
A neglected property is the signal of a neglected community. Once established, the public opinion will worsen the reputation and the image of the area, provoking further decay and abandonment. The decline of the social housing estates can indeed be described as a vicious circle.
In such a situation, renewal of a neighbourhood is a sensitive social issue and it is in the current agenda of many European countries.
Nevertheless, there are serious concerns about the feasibility and the efficacy of these interventions, and many barriers and constraints need to be considered in the process. In many cases, understanding the local context with its complex socio-economic-cultural condition is a key driver of what in this thesis is described as “best practice”.
The strategy based on the use of “adaptive exoskeletons” prepare the ground for these interpretations, providing a solid framework to develop flexible and adaptable solutions.
This chapter will consider some of the most common considerations connected to urban renovation and building retrofitting. The economic feasibility of the proposal will be considered, in particular in relation to the use of the shape memory alloys-based dissipative devices. Issues connected with energy performances will be also discussed in this chapter. The proposal will be considered also in relation to the new idea of “changing architecture”, which will involve the façade, one of the most expressive element of the construction. The barriers and constraints of the intervention will be also evaluated, and, finally, the thesis will evaluate the possibility to apply the design concept to other fields of actions.

9.2 Economic considerations

The probability of a real estate market failure is rising consistently in the last years and despite stringent targets, the building sector is unable to transform the new challenges into opportunities, because of the inadequate supply or for the high demand.

Reducing the probability of a major market failure requires that all the stakeholders of the building sector (manufacturers, constructors, energy service companies) focus and deepen their interest in retrofitting the existing heritage.

Consequently, the retrofit market needs to be interpreted, to make able the construction industry to provide the proper supply to develop an actual market.

This can be even more effective in concurrence with “economies of scale” applied on large-scale recovering programmes of post Second World War social housing estates, where “light” techniques based on sustainable solutions can be applied to “mass retrofit”.

The concept was firstly expressed by Druot, Lacaton and Vassal, who compared the economic effects between demolition/reconstruction and retrofit.

The study underlined as demolition and reconstruction of a certain floor area can have a cost up to ten times higher than a basic retrofit. So one intervention of demolition/reconstruction could be substituted by the refurbishment of three times the same floor area for 50.000 euro per dwelling, five times the same floor area for 33.500 euro per dwelling, and up to eight times the same floor area for 17.000 euro per dwelling.

Another relevant reason to adopt these “economies of scale” is that most of the technological solutions are today still too expensive, and require long-span intervention campaign to reduce the effect of unit-manufacturing costs. The construction processes lack productivity and quality, so that the most promising technologies will deliver savings only if their building integration has been carried out properly and controlled step by step. Innovation on construction processes need to find reliable approaches where existing gaps between performance by design and performance at commissioning are narrowed down.

This is exactly the case of the implementation of “smart materials” in innovative structural designs.

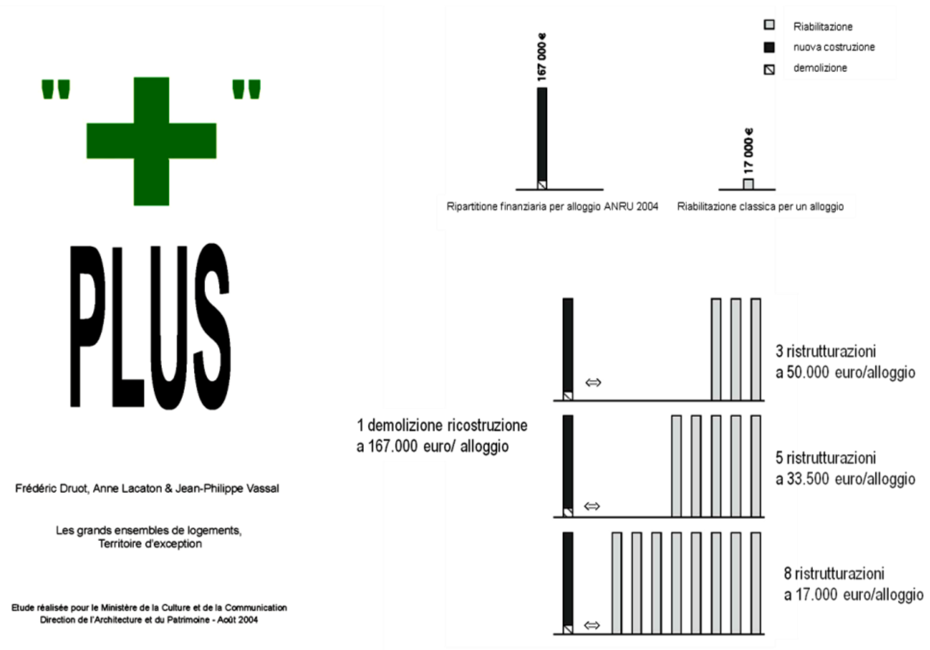


Figure 9.1
Druot, Lacaton and Vassal’s theory about “economies of scales”.

Due to the size of civil engineering structures and the acting of relatively high forces, a large amount of material is needed compared to applications in other fields, such as medical technology (Alam et al., 2007).
Despite the good properties of the shape memory alloys, the high material costs prevent extensive applications. A viable solution is to use the alloys only in smaller devices or in selected regions of the structure (Janke et al., 2005).
In the past, many studies have been conducted in order to assess the practical feasibility and economic convenience of this technology (Dolce & Marnetto, 2000).
With reference to bracing systems for framed structures, apparently the cost of SMA is negligible with respect to the cost of the dissipative device. Consequently, the cost of SMA braces is practically identical to the cost of the common steel braces.
From these studies, it appears that the use of SMA-based passive control systems, other than providing better performances, does not imply higher costs if compared to current passive control systems (Dolce et al.,2000a; Bruno & Valente, 2002).
It is also undeniable that the cost of shape memory alloy in the last years has decreased significantly, due to increased demands and improvements in manufacturing techniques (Frick et al., 2004).
In addition, it is reasonable to assume that the price will continue to drop down as further applications using large quantities are developed, such in the case of civil engineering filed (DesRoches et al., 2004).

9.3 Issues connected with performances and energy saving

The motivation to improve the existing building stock lies in society's efforts towards sustainable development, with the housing sector playing an important role, with approximately 40% of the energy consumed in EU.
Energy is a key issue to ensure a sustainable development, as the use of energy is largely connected with the depletion of fossil fuels and climate change.
Energy in households is consumed for heating, cooling, DHW, cooking and appliances. Space heating is the most intense end-use in Europe, which is typically less in the southern countries, with warmer climate.
It is evident that the older part of the building stock tends to consume more, contributing greatly to the high-energy use of the building sector. While buildings dated after the Second World War are characterized by a mix of construction techniques and typologies, they all have in common the poor energy performances (Itard, 2008). This is because the techniques used at the time of construction had lower performance and efficiency standards. It is also indicative of the huge potential to improve the performance and reduce the energy demand by retrofitting. Energy efficiency is a major concern in the residential buildings of that period, particularly when considering social conditions such as "fuel poverty" for households of low incomes (BPIE, 2013).
An increase in building energy performance could constitute an important instrument in the efforts toward alleviating the EU's energy import dependency and reach targets for the reduction of carbon dioxide emissions. The potential of refurbishment to upgrade the energy efficiency of the building stock and the resulting cuts in CO2 emissions has been addressed by both the building industry and research.
It has been stated that deep renovation achieving savings between 60% and 90% has the potential to reach the decarbonisation targets for 2050, and they are therefore preferred solution from an ecological and economic point of view (Hermelink & Muller, 2011). A deep renovation typically adopts a holistic approach, viewing the renovation as a package of measures working together, as oppose to moderate renovation, involving 3-5 improvements resulting in reductions of 30-60%.
Although the potential has been identified, guidelines come in the form of general suggestions, unable to address the diversity of each situation. In practice, the implementation of the measures has to suit the individual

project (Nemry et al., 2010), in terms of the building's existing condition, location, project specifications, budget, client's requirement and designer's decisions.

In many European countries, new technologies have been actually developed, but these often are used only locally to achieve a higher quality in urban buildings. This results in a limited overall impact on urban environments, where problems and solutions are approached in isolation.

The wish to improve the quality of an individual building usually leads to a local, project-based solution. Solving the specific problems of this renovation-project becomes the sole target. To reach maximum value for money, it is essential to integrate all the factors influencing urban building envelopes and look at them in a broader scope (Di Giulio et al., 2007).

In addition, refurbishment of the aging residential buildings is a complicated task encompassing a number of parameters such as the architectural design, construction and energy efficiency, along with political support and incentives, socio-financial effects and users' behaviour. The design process needs to address all different parameters, which ultimately define the decisions to be taken.

Throughout this process and the various constrains to be considered, often energy upgrade is not one of the main consideration. Even though it is part of the project requirements, it is typically calculated towards the end of the design process, in the form of regulatory or voluntary certificates (Dakwale et al., 2011) mostly to be used for official and marketing purposes. In this way, the performance evaluation comes after the strategy has been developed, without influencing the decisions made.

However, the earlier the design decisions are made, the bigger impact with lower cost they can have, because the potential to influence substantial decisions related to construction and operating costs is the highest in the early design process (Bogenstatter, 2000)

Evaluation of the performance has proven to be very effective while decision-making amongst various available options (Dakwale et al., 2011). If the designer is provided with an indication of how efficient refurbishment measures are, it is possible to apply them as part of an integrated strategy rather than try to add measures at later stages, after the strategy has been developed. During the early design stages the benchmarking and the possibility to compare alternatives.

Most existing tools do not emulate this process and focus on post-design evaluation (Attia, 2012).

In order to be able to assess the energy performance of the refurbished building at the early stages of the design phase, we first need to address the building component that is the most influential with regard to energy consumption. This is the building facade, or rather the building envelope.

The building envelope is the space enclosure element and it consists of components such as external wall, windows, roof and ground floor (Konstantinou, 2014). The facade is the main element of the architectural expression and the key feature of the building, but, most importantly, it also regulates the energy use and the indoor condition.

The energy consumption is directly related to heat losses through building envelope components, ventilation and air infiltration and inversely related to heat gains in the building through solar radiation, all parameters that depend on the design, quality and function of the external envelope of the building.

For refurbishment, the diversity of architectures and climates in Europe requires a whole value chain innovation process where design, technology choice and construction are even more intertwined than for new buildings (Ad Hoc, 2012).

The "adaptive exoskeleton" evaluates the necessity to respond to the agenda of the European countries in a completely new way.

The integration of energy efficient materials and systems in the new envelope describe an adaptive behaviour, because every components can be independently updated if new requirements occur or when new technologies are available.

The most innovative solutions can be applied time after time, eradicating the problem at the origin, namely adding a dimension of temporariness to the design choices.

9.4 Barriers and constraints

In simple economic terms, the fact that there is a large unused cost-effective potential for improving the performance of buildings is evidence that consumers and investors, as well as society in general, are not keen on investing in innovation in the construction sector. The human dimension combined with a variety of other factors that affect the retrofit market need to be understood and addressed to achieve successful strategies.
Experience over decades has identified several barriers that can prevent or delay the uptake of renovation measures.
These barriers are classified in the report "Europe's Buildings under the microscope" (BPIE, 2011) as financial, institutional/administrative, related to awareness, advice and skills or to the separation of expenditure and benefit.

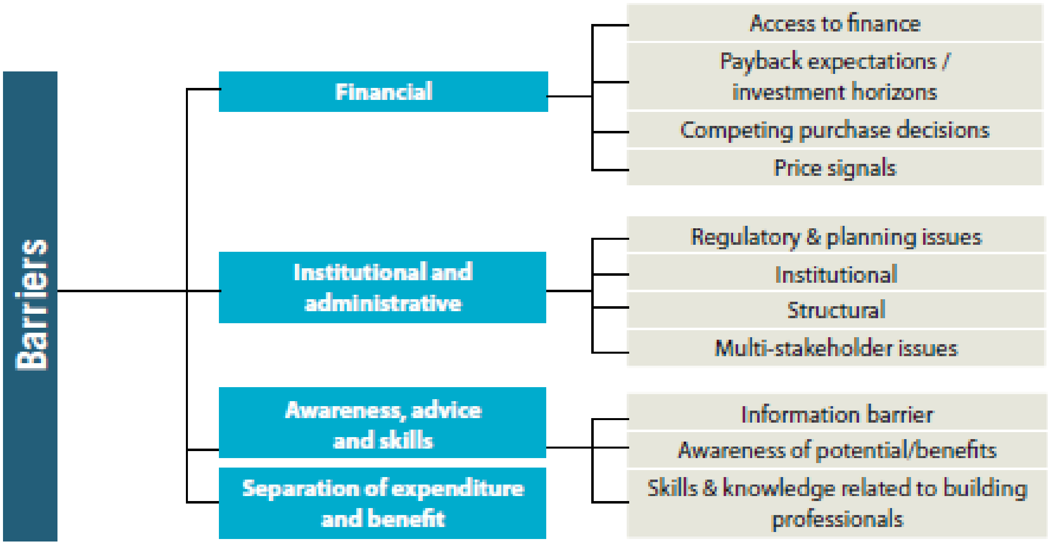


Figure 9.2

Barriers to the uptake of renovations. (Source: BPIE, report 2011).

Any renovation requires an investment and, therefore, financial barriers are a top priority. The lack of funds is the most cited argument that prevents investment on retrofit programmes. Although the measures will be cost effective in the long term, the initial cost can be an obstacle for the decision. Sometimes the payback period may exceed the period they plan to stay in the house.
To tackle this problem, upfront funding and other financial incentives are necessary. The role of available financial programmes and innovative mechanisms becomes increasingly important.
In addition to financial barriers, there is a wide range of administrative issues. The degree of housing privatisation can be an important barrier to refurbishment. In the case of privately owned stock, especially privately let stock, greater economic incentives are necessary. It may also prove hard to achieve resident consensus. Generally, public ownership would allow for a greater degree of control, making it easier to coordinate and carry out decisions on refurbishment, in particular with respect to the incorporation of energy efficiency measures (Waide et al., 2006).
Another concern regarding the speed and depth of renovation is lack of adequate advice and technical expertise. Compared to large-scale new construction, working in existing dwellings requires completely different skills regarding technical, social and managerial artisanship, as well as the type, size and organization of the company.

This also applies to designers, developers, commissioners and governments, whose knowledge about how and when to successfully maintain, manage, adapt, transform and redesign older stock has still to improve (Thomsen, 2011).
In addition to these barriers, Sandivo (1991) identifies four main constraints that renovation projects face throughout the construction process: time, space, information and environment. These constraints affect the performance of the project in terms of schedule, budget, and scope of work.
Time is a constraint on almost every construction project because, in essence, time is money. However, with sustainable renovation projects, time can play a more intricate role in determining the success of the project. Contractors involved in reconstruction projects are sometimes given a shorter and more exact time frame within which all work must be completed. Many renovation projects must be completed during a narrow window of opportunity during a facility closure (Sandivo, 1991). In such a project, the contractor has only a few months to complete the work. If the project isn't properly executed and variables such as weather, unforeseen conditions, material delivery, and subcontractor organization have not been accounted for, then the contractor has a greater risk of finishing behind schedule and over budget. Another example of a project with a time constraint is one where an owner relocates and rents a separate building during the renovation.
Another constraint of nearly all renovation projects is space. Like time, space may be a constraint for new construction projects as well; however, it is usually a constraint for a renovation project. Space congestion may also introduce problems of laydown areas, access to the facility for construction workers, and work sequencing of specific equipment (Sandivo, 1991). The physical space of a jobsite varies for every reconstruction project but in most cases, the existing conditions of the building may limit the design from satisfying the function required by the owner. Challenges such as the coordination of material delivery and storage require detailed planning and scheduling in order to reduce congestion on the construction site (McKim et al. 2000). Limited space also introduces the concept of project disturbance. Disturbance generally refers to the negative impacts that influence the construction operation as well as the existing facilities operation. Therefore, on a sustainable renovation construction site, two types of disturbances are present: (1) the disturbance of infrastructure functions due to construction, and (2) the disturbance of construction functions due to infrastructure (Shami & Kanafani, 1997). An example of disturbance of infrastructure functions due to construction is a situation where construction noise and air pollution, due to improper quality control measures, cause the occupants of a nearby building to become uncomfortable and distracted. Similarly, construction productivity may be deterred due to infrastructure functions in an example where the limited parking spaces that provide construction site access for materials and equipment are occupied by building tenants.
Available information about the existing facility and site history will vary for all reconstruction projects. In many cases, adequate as-built drawings and limited information about the existing structure may decrease productivity and delay construction. Additionally, demolition work often reveals conditions that cannot be reasonably foreseen. In such a case, the initial plans developed for the project do not correspond with the existing conditions, which can only be completely investigated during demolition (Krizek et al., 1996). Therefore, it is important to have a structured plan set forth during the project delivery phases of how the contractor, owner, and designer must proceed after encountering an unforeseen condition.
Renovation projects are more susceptible to health and safety risks than new construction projects mostly because working within an occupied building or enclosed structure imposes additional constraints and restrictions for safe practices. Environment is constrained by extreme temperature and weather conditions, working with hazardous or toxic materials, and construction noise and vibration (Sandivo, 1991). Health and safety risks typically originate from two sources in renovation projects. First, during the renovation of an outdated, dilapidated building, the contractor is likely to encounter existing building components that contain hazardous materials such as asbestos, polychlorinated biphenyl, or lead. The removal and handling of these materials must be performed using the proper safety equipment and measures. Second, similar to the space constraint, the building occupants impose constraints on activities and equipment that produce air or noise

pollution. If not properly planned for in the early stages of the project, these environmental concerns may result in cost and schedule overruns (McKim et al., 2000).

Constraints and barriers can both be removed through careful front-end planning and wise decision-making early in the project delivery (Gibson et al., 2007).

A common problem for retrofit programme is indeed connected to conditions identified late in the design process, that may have several impacts on the renovation project (Mitropoulos & Howell, 2002), such as affecting the cost and time required or limiting the design options. A possible solution is to identify project constraints that design and construction have to meet early in the planning phase and accelerate the discovery of existing conditions.

Another problem can occur when there is no interaction between the design of the systems (Olgyay & Seruto, 2010). Whole-systems thinking is an interdisciplinary approach to analysing how the various building systems and components interrelate with each other in order to maximize the benefits available in a building renovation project.

It is also true that industry lacks experience with the processes and knowledge required to perform deep retrofits (Olgyay & Seruto, 2010). Only a small portion of practicing designers can be considered experienced in integrating current energy-efficient and sustainable options into existing buildings.

One reason for that is that education for industry professionals is more focused on traditional practice rather than on how to integrate into design continuing advances and innovative techniques made on a holistic scale.

Another reason for lack of knowledge is companies involved with renovation projects tend to assign inexperienced people in the well meaning effort to provide them with valuable experience. These young and inexperienced project team members may potentially impact the project in a negative manner (Sandivo, 1991).

Although re-educating design and construction professionals throughout the industry will take decades, it is imperative for these professionals to deviate from traditional methods in order to learn innovative tools and techniques that optimize cost and performance. Simultaneously, emerging green technologies and design options for improving building performance will continue to rapidly evolve. Therefore, today's design and construction professionals must have access to current user-friendly systems that ask the right questions, in the right sequence, to produce optimal solutions.

Also many building owners have misconceptions about sustainable renovation especially regarding financial issues such as perceived higher first costs. Also, green washing plays a significant role in misleading owners and tenants about sustainability issues. Green washing is when consumers are misinformed about the environmental practices of a company or the environmental benefits of a product through misleading advertising. Educating the end-user on behavioural issues that impact building performance is a possible solution to overcoming this barrier.

9.5 Discussion

The industrial heritage has become a valuable asset to be used to regenerate declining urban areas and promote a more desirable place image. Since historic buildings contribute immensely to the attractiveness, distinctiveness and identity of places (Mengüşoğlu & Boyacioğlu, 2013).

Current urban polices strongly support the concept of preserving and reusing these buildings and their surroundings to create more sustainable, high quality, mixed use, high-density and historic neighbourhoods.

Many industrial cities now experience the same kind of reuse schemes converting former industrial buildings into places of living, leisure and consumption.

The urban planning and architectural term for restoring old and obsolete buildings into new uses is "adaptive reuse". Adaptation or adaptive reuse occurs when a building is no longer performing, or intending to perform,

its designated function (Kincaid, 2003). The conversion of obsolete structures, originally intended for other uses, into other spaces has been manifested in multiple combinations of new uses.
Adaptive reuse revises the function of a building while preserving the integrity of architectural space. In order for a building to accommodate change, it must have a functional value as well as a commodity value. Buildings that offer an open arrangement of spaces and a flexible structural framework have the best potential for reuse.
Adaptive reuse gives new life to a site, rather than seeking to freeze it at a particular moment in time. It explores the options that lie between the extremes of demolition or turning a site into a museum. Adding a new layer without erasing earlier layers, the intervention becomes another stage, not the final outcome.
Heritage best practice is for new work to be able to be removed at a later date, so that adaptive reuse does not preclude future conservation.
Adaptive reuse also has the potential to add value in other ways. It can, for example, be part of an effective heritage led regeneration strategy for a wider area. It is important to remember that adaptive reuse is not restricted to individual buildings or small precincts.
Adaptive reuse is not simply a matter of retaining the fabric or envelope of buildings. The heritage building, site or precinct needs to be understood in complex ways. Other aspects to be considered include the spatial structures and configurations, the relationship between the site and its context, significant views to, from and within the site, and traces of activities and processes.
Many industrial heritage sites are reused as facilities for the arts and creative industries. The aesthetic of industrial places is often readily compatible with arts uses and the building fabric can often be retained with the patina built up over time.
Adapting industrial sites for multi-residential reuse can have much more significant impacts than other uses.
For example, large spaces are carved up into smaller units and new services, such as plumbing, installed.
Heritage buildings are often adapted as high-end residential developments, which may result in building fabric being over-restored, over-cleaned or hidden behind new walls. However, changing expectations mean that many residents now appreciate the industrial aesthetic and patina of building fabric. Heritage qualities particular to a place are now often understood as a desirable attribute for a particular market. These attributes are increasingly used as part of the marketing of residential reuse projects. Although residential reuse can be more difficult, it can be done very successfully in response to particular site features.
Not all adaptive reuse is costly and some highly effective, low-impact reuses can be achieved on tight budgets.
It is very difficult to achieve good adaptive reuse without an engaged client and an effective process. Adaptive reuse needs to be supported by clear documents that guide the redevelopment and future use.
Again, the “adaptive exoskeleton” could be a viable structural solution to apply large-scale campaign of intervention, with the challenge to face completely different backgrounds and realities.
In some extreme cases, an “endoskeleton” could be the more effective solution to provide an appropriate framework to the “adaptive reuse” to happen.
To summarize the proposal aims at continuing the broad study undertaken in the field of integrated retrofit of social housing buildings, amplifying the possible fields of application and finding new research directions in the field of the “adaptive reuse” of industrial sites.
The structural tool called the “adaptive exoskeleton” is the framework around which new theories and practice can be developed.
The solution exploits dry-construction technologies in order to allow cheap and easy future modifications, trying to anticipate the necessities of the future communities.
The study of the interaction between the existing structure and the new one is fundamental to verify the applicability of the proposal, and it will require detailed numerical analyses with the use of finite elements models.

10. RETROSPECTIVES AND PERSPECTIVES

This thesis suggested a vision of an architecture in which buildings can change shape, appearance, and configuration in response to the socio-economic, cultural, and technological context.

The quest for an “architecture of change” is a reflection of the expectation of the current society that embraces the transience in today living style.

We are the most news-centric generation ever, ruled by new trends and forces of change (Kolarevic, 2009).

New technologies and design solutions allow to create architectures able to mirror this new culture of shifting, providing tools for temporariness.

In this context retrofit plays a fundamental role in denying deny the dimension of permanence typical of the traditional architecture, allowing the construction to co-evolve with its user and environment.

This research presents a long-term strategy of integrated retrofit for social housing stock, providing a solution consistent with current architectural, functional, and structural standards, but able to change progressively and continuously.

To meet this aim, three main research questions were formulated. In this chapter, the author will briefly summarize the conclusions of the research in relation to these questions.

Q1: Which integrated approach of building retrofit could solve within the same intervention the complex and delicate conditions of social housing stock?

The “adaptive exoskeleton” is an integrated structure for retrofitting, able to operate within the same intervention on architectural, structural and functional aspects of the building.

It is an enveloping frame, built with dry-construction systems, which wraps the existing construction providing new performances and features. In some cases, it can be equipped with dissipative devices, realized using shape memory alloys, in order to allow an anti-seismic behaviour.

The frame can be two or three-dimensional, is relation to the surrounding limitations or to urban regulations. In the last case, the new space provided can be allocated to the dwellings, creating new balconies, terraces, winter gardens, etc., or it can be used to create new accessibility patterns modifying the whole building typology. The consequent increase in the value of the property makes this intervention of retrofitting a possible investment to capitalize, instead of a mere expense.

The intervention acts directly on the envelope of the construction, redefining the energy performances but also the aesthetical quality of the building and of the neighbourhood, providing a new environmental and social quality.

Q2: Which strategies allow a long-term use, in terms of life cycle extension of the constructions but also in relation of the changing needs and requirements of a dynamic society?

The adaptable behaviour of the “exoskeleton” is due to a strict separation between the base elements, namely the structural frame with the seismic devices, and the infill, which is designed to be progressively substituted.

This principle is convenient in large-scale campaigns, where it is necessary to create a solid base structure without renouncing to the individualization and the variety of the demand, overcoming the problems of visual monotony which always characterize social housing estates.

This strategy also stimulates the introduction of architectural components with a shorter usable-life, requiring high degree of prefabrication and optimization. Once a single component is not required anymore in a building, it can be disassembled and re-manufactured for further use in the building sector, providing a sustainable cradle-to-cradle cycle. The idea is to empower the users of the possibility to design the dwellings, providing a catalogue or platform of possible options and choices. In this way, it is also possible to exploit the benefits provided by an industrialized production to obtain economic constructions.
The flexibility provided helps the building to become able to respond to users' requirements and environmental needs in a long-term vision, promoting an ideally never-ending life cycle extension.

Q3: Which is the role of the newer technologies and techniques in defining new sceneries for social housing retrofit?
The construction industry is reticent to change, while new technologies and techniques allow today innovative solutions to handle historical problems, such as the demand for affordable housing.
The use of the full potential of these new methods can disclose new sceneries for a sector in crisis, opening to new horizons of development.
The new technical and technological knowledge facilitates the management and monitoring of more complex architectures in every phase of their design process, passing by material analysis, external interactions (environmental and human) and form finding. Nowadays, these tools allow moving away from the past uniformity and rigidity.
A possible solution is to use technology to create a framework for flexible housing to develop, abandoning the idea of a strict determinism and allowing a certain degree of "controlled freedom".
This strategy exploits technology to create structural systems, in form of expressed frames or grid structures, able to accept further and progressive changes.

In conclusion, this doctoral thesis presents technical strategies for the rational maintenance of the building heritage directed at the architectural recovering and reconfiguring of social housing stock and it evaluates the necessity to define new design practices for the requalification of "suffering" objects. These objectives can be achieved with limited economic and social costs, using appropriate technologies to satisfy different target users, to improve the performances and the quality of the spaces.
The realization of proportional-economies constitutes an efficient strategy when it privileges the use of sustainable materials, the optimization of energy exchanges and the adoption of "light" techniques finalized to the seismic and structural retrofit.
This research underlined the convenience of applying retrofit processes in opposition with demolitions and reconstructions, above all in terms of social and environmental costs.
Further developments will consider the application of the same principles for the adaptive reuse of abandoned areas, a fundamental direction to follow in order to provide a sufficient and sustainable housing supply for future generations.

11. BIBLIOGRAPHY

Acharya, L. (2013). Flexible architechture for the dynamic societies: reflection on a journey from the 20th Century into the future.

Ad-Hoc, I. A. (2012). Energy-efficient Buildings PPP beyond 2013: Research & Innovation Roadmap Energy Efficient buildings. Brussels: Energy Efficient Buildings Association.

Alam, M. S., Youssef, M. A., & Nehdi, M. (2007). Utilizing shape memory alloys to enhance the performance and safety of civil infrastructure: a review.*Canadian Journal of Civil Engineering*, *34*(9), 1075-1086.

Al-Chaar, G. (2002). *Evaluating strength and stiffness of unreinforced masonry infill structures*. Paper for the US Army Corp of Engineers, Engineer Research and Development Center.

Aldersey-Williams, H. (2004). Towards biomimetic architecture. *Nature materials*, *3*(5), 277-279.

Andersen, H. S. (2003). *Urban Sores. On the Interaction between Segregation, Urban Decay and Deprived Neighbourhoods*. Ashgate.

Andeweg, M. T., Brunoro, S., & Verhoef, L. G. (2007). *Cost C16, Improving the Quality of Existing Urban Building Envelopes: State of the Art* (Vol. 1). IOS Press.

Arieff, A. (2002). *Prefab*. B. Burkhart (Ed.). Gibbs Smith Publishers.

Attia, S. (2012). A Tool for Design Decision Making Zero Energy Residential Buildings in Hot Humid Climates. (Doctorate). Universite catholique de Louvain, Louvain.

Auricchio, F. (1995). *Shape-memory alloys: applications, micromechanics, macromodelling and numerical simulations*. University of California, Berkeley, Dec. 1995.

Auricchio, F., & Sacco, E. (1997). A one-dimensional model for superelastic shape-memory alloys with different elastic properties between austenite and martensite. *International Journal of Non-Linear Mechanics*, *32*(6), 1101-1114.

Auricchio, F., Fugazza, D., & Desroches, R. (2006). Earthquake performance of steel frames with nitinol braces. *Journal of earthquake engineering*, *10*(spec01), 45-66.

Auricchio, F., Fugazza, D., & DesRoches, R. (2007). A 1D rate-dependent viscous constitutive model for superelastic shape-memory alloys: formulation and comparison with experimental data. *Smart materials and structures*, *16*(1), S39.

Auricchio, F., Fugazza, D., & Desroches, R. (2008). Rate-dependent thermo-mechanical modelling of superelastic shape-memory alloys for seismic applications. *Journal of Intelligent Material Systems and Structures*, *19*(1), 47-61.

Balaras, C.A., Droutsa, K., Dascalaki, E. & Kontoyiannidis. S. (2005). Deterioration of European apartment buildings. *Energy and Buildings* 37 (2005) 515–527

Ball, M. (2011). RICS European housing review 2011. *Published by RICS Royal Institution of Chartered Surveyors. Available at http://www. rics. org/site/download_feed. aspx*.

Bar-Cohen, Y. (2006). Biomimetics—using nature to inspire human innovation. *Bioinspiration & Biomimetics*, *1*(1), P1

Bassani, P., & Besseghini, S. (2001). Martensites in NiTi and NiTiCu alloys-NiTiCu shape memory alloy: Superplastic elongation during thermal cycling. *Journal de Physique-Colloques*, *11*(8), 381-386.

Baumeister, D. (2007). Biomimicry. *Presentation at the University of Washington College of Architecture*. Seattle, USA.

Bennicelli Pasqualis, M. G. (2014). *Case temporanee. Strategie innovative per l'emergenza abitativa post-terremoto*. Collana Ricerche di tecnologia dell'architettura 1a edizione. Franco Angeli editore.

Bhushan, B. (2009). Biomimetics: lessons from nature–an overview. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, *367*(1893), 1445-1486.

Braga, F., & Dolce, M. (1982). Un metodo per l'analisi di edifici multipiano in muratura antisismici. *Proc. Of the 6th IB Ma. C., Roma*, 1088-1099.

Brand, S. (1995). *How buildings learn: What happens after they're built*. Penguin.

Brinson, L. C. (1993). One-dimensional constitutive behavior of shape memory alloys: thermomechanical derivation with non-constant material functions and redefined martensite internal variable. *Journal of intelligent material systems and structures*, *4*(2), 229-242.

Bruno, S., & Valente, C. (2002). Comparative response analysis of conventional and innovative seismic protection strategies. *Earthquake engineering & structural dynamics*, *31*(5), 1067-1092.

Bogenstatter, U. (2000). Prediction and optimization of life-cycle costs in early design. *Building Research & Information*, 28(5-6), 376-386.

Bucchi, F., Arangio, S., & Bontempi, F. (2013). Seismic assessment of an historical masonry building using nonlinear static analysis. In *Proceedings of the fourteenth international conference on civil, structural and environmental engineering computing. Paper* (Vol. 72).

Building Performance Institute Europe BPIE (2011). Europe's Buildings under the Microscope.

Building Performance Institute Europe BPIE (2013). A Guide to Developing Strategies for Building Energy Renovation: Delivering the Energy Efficiency Directive Article 4 Brussels: Building Performance institute Europe.

Burton, E., Jenks, M., & Williams, K. (Eds.). (2003). *The compact city: a sustainable urban form?*. Routledge.

Caffrey, R. J. (1988). *The Intelligent Building: An ASHRAE Opportunity*. ASHRAE.

Castellano, M. G., Medeot, R., Forni, M., Indirli, M., Martelli, A., Spadoni, B., & Venturi, G. (1997). Seismic Protection of Cultural Heritage through Shape Memory Alloy-Based Devices.

Castellano, M. G., Indirli, M., & Martelli, A. (2001). Progress of application, research and development, and design guidelines for shape memory alloy devices for cultural heritage structures in Italy. In *SPIE's 8th Annual International Symposium on Smart Structures and Materials* (pp. 250-261). International Society for Optics and Photonics.

Caterino, N., Iervolino, I., Occhiuzzi, A., Manfredi, G., & Cosenza, E. (2007). Dissipazione passiva nella selezione dell'intervento di adeguamento sismico di un edificio in ca mediante analisi decisionale. *L'Ingegneria Sismica in Italia–XII Convegno Nazionale dell'ANIDIS, Pisa, Italy*.

Caterino, N., Iervolino, I., Manfredi, G., & Cosenza, E. (2008). Multi-criteria decision making for seismic retrofitting of RC structures. *Journal of Earthquake Engineering*, *12*(4), 555-583.

Causevic, M., & Mitrovic, S. (2011). Comparison between non-linear dynamic and static seismic analysis of structures according to European and US provisions. *Bulletin of earthquake engineering*, *9*(2), 467-489.

Chapman, T. J. P., Chow, F. C., & Skinner, H. (2002). Building on old foundations–sustainable construction for urban regeneration. In *CEWorld Conference*.

Cheung, M., Foo, S., & Granadino, J. (2000). Seismic retrofit of existing buildings: innovative alternatives. *Public works and government services, Canada*, 1-10.

Chusid, M. (1993). Once is never enough. *Building Renovation*, (March-April), 7-20.

Cimellaro, G. P., Reinhorn, A. M., & Bruneau, M. (2010). Framework for analytical quantification of disaster resilience. *Engineering Structures*, *32*(11), 3639-3649.

Clark, P. W., Aiken, I. D., Kelly, J. M., Higashino, M., & Krumme, R. (1995). Experimental and analytical studies of shape-memory alloy dampers for structural control. In *Smart Structures & Materials' 95* (pp. 241-251). International Society for Optics and Photonics.

Cody, B. (2014). The Role of Technology in Sustainable Architecture. In *Wolkenkuckucksheim, Internationale Zeitschrift zur Theorie der Architektur*. Vol. 19, Issue 33, p. 239–249.

Croci, G. (2001). Strengthening the basilica of St Francis of Assisi after the September 1997 earthquake. *Structural engineering international*, *11*(3), 207-210.

Crump, J. (2012). *Demolition*. In: International Encyclopedia of Housing and Home. Elsevier.

D'Amico, A., & Currà, E. (2014). Urban Resilience and Urban Structure: Vulnerability assessment of historical Italian towns. Paper presented at the ANDROID Residential Doctoral School.

Dakwale, V. A., Ralegaonkar, R. V., & Mandavgane, S. (2011). Improving environmental performance of building through increased energy efficiency: A review. *Sustainable Cities and Society*, 1(4), 211-218.

Davis, S. (1997). *The architecture of affordable housing*. University of California Press.

Deierlein, G. G., Reinhorn, A. M., & Willford, M. R. (2010). Nonlinear structural analysis for seismic design. *NEHRP Seismic Design Technical Brief No*, *4*.

De Jonge, T. (2005). *Cost effectiveness of sustainable housing investments*. TU Delft, Delft University of Technology.

De Rossi, A. (2004). Programmi complessi e qualità del progetto urbano. In: Ferrero, G. (Ed.), *Valutare i programmi complessi*. L'Artistica Editrice.

DesRoches, R., McCormick, J., & Delemont, M. (2004). Cyclic properties of superelastic shape memory alloy wires and bars. *Journal of Structural Engineering*, *130*(1), 38-46.

DesRoches, R., & Smith, B. (2004). Shape memory alloys in seismic resistant design and retrofit: a critical review of their potential and limitations. *Journal of Earthquake Engineering*, *8*(03), 415-429.

Diamant, R. M. E. (1965). *Industrialised building 2: 50 international methods*. Iliffe Books Ltd.

Di Biagi, P. (Ed.) (2001). *La grande ricostruzione: Il piano Ina-Casa e l'Italia degli anni cinquanta*. Donzelli Editore.

Dietz, A. G. H. (1992). *Dwelling House Construction*. Mit Press.

Di Giulio, R., Bozinovski, Z., & Verhoef, L. G. (2007). *Cost C16, Improving the Quality of Existing Urban Building Envelopes: Structures* (Vol. 3). IOS Press.

Dixit, M. K., Fernández-Solís, J. L., Lavy, S., & Culp, C. H. (2010). Identification of parameters for embodied energy measurement: A literature review. *Energy and Buildings*, *42*(8), 1238-1247.

Dolce, M., Cardone, D., & Nigro, D. (2000a). Experimental tests on seismic devices based on shape memory alloys. *Stress (N/mmq)*, *500*, 750.

Dolce, M., Cardone, D., & Marnetto, R. (2000b). Implementation and testing of passive control devices based on shape memory alloys. *Earthquake engineering & structural dynamics*, *29*(7), 945-968.

Dolce, M., & Marnetto, R. (2000). Passive seismic devices based on shape memory alloys. In *12th World Conference on Earthquake Engineering*. Paper No 2386.

Dolce, M., & Cardone, D. (2001). Mechanical behaviour of shape memory alloys for seismic applications 2. Austenite NiTi wires subjected to tension. *International Journal of Mechanical Sciences*, *43*(11), 2657-2677.

Dolce, M., Cardone, D., Ponzo, F. C., & Valente, C. (2005). Shaking table tests on reinforced concrete frames without and with passive control systems. *Earthquake engineering & structural dynamics*, *34*(14), 1687-1717.

Dolce, M. (2009). Mitigation of Seismic Risk in Italy Following the 2002 S. Giuliano Earthquake. In *Earthquakes and Tsunamis* (pp. 67-89). Springer Netherlands.

Dolce, M. (2012). The Italian National Seismic Prevention Program. In *Proc. of 15th World Conference on Earthquake Engineering* (pp. 24-28).

Dooley S. (2004). The development of material-adapted structural form. EPFL-CCLab PhD-thesis No. 2986

Duerig, T. W., Pelton, A., & Stöckel, D. (1999). An overview of nitinol medical applications. *Materials Science and Engineering: A*, *273*, 149-160.

Echavarria, P. (2004). *Portable Architecture and Unpredictable Suroundings*. Links Internacional.

Egan, Sir J. (1998). *Rethinking Construction*. Department of the Environment, Transport and the Regions, London

Egbelakin, T., & Wilkinson, S. (2008). Factors affecting motivation for improved seismic retrofit implementation. In *Australian Earthquake Engineering Conference (AEES)*.

Emmanuel, R., & Baker, K. (2012). Carbon Management in the Built Environment. Routledge.

FEMA 306 (1998). Applied Technology Council (ATC-43 Project). Evaluating of Earthquake Damaged Concrete and Masonry Wall Buildings.

FEMA 356, ASCE. 2000. *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*.

Finley, D. T., & Cribbs, R. A. (2004). Equivalent static vs. response spectrum: a comparison of two methods. In *SPIE Astronomical Telescopes + Instrumentation* (pp. 403-410). International Society for Optics and Photonics.

Fistola, R., & La Rocca, R. A. (2009). Metodi expert knowledge based per la definizione del rischio globale urbano (GURU). In *Atti della XXX Conferenza Italiana di Scienze Regionali, Firenze* (pp. 9-11).

Forty, A. (2000). *Words and buildings: a vocabulary of modern architecture* (Vol. 268). Thames & Hudson.

Frampton, K. (1980). *Modern Architecture: A Critical History.* Oxford University Press.

Frick, C. P., Ortega, A. M., Tyber, J., Gall, K., & Maier, H. J. (2004). Multiscale structure and properties of cast and deformation processed polycrystalline NiTi shape-memory alloys. *Metallurgical and Materials Transactions A*, *35*(7), 2013-2025.

Friedman, Y. (1960). *Architecture Mobile*.

Friedman, Y., Trobaugh, W., & Roullier, E. (2006). *Pro domo*. Actar.

Fugazza, D. (2003). Shape-memory alloy devices in earthquake engineering: mechanical properties, constitutive modelling and numerical simulations. Doctoral dissertation, Istituto Universitario di Studi Superiori di Pavia.

Fukuyama, H., & Sugano, S. (2000). Japanese seismic rehabilitation of concrete buildings after the Hyogoken-Nanbu Earthquake. *Cement & Concrete Composites* 22: 59-79.

Fusier, F., & Vignoli, A. (1993). Proposta di un metodo di calcolo per edifici in muratura sottoposti ad azioni orizzontali. *Ingegneria Sismica*, X, 1.

Gargiulo, C., & Papa, R. (1993). Caos e caos: la città come fenomeno complesso. *Per il XXI Secolo: una enciclopedia e un progetto*, 297-306.

Gibson, G. E., Cui, Q., Howard, S., & Irons, K. T. (2007). Front end planning for renovation projects. In *Proceedings of the Construction Research Conference*.

Giddens, A. (1991). *Modernity and self-identity: Self and society in the late modern age*. Stanford University Press.

Giebeler, G., Krause, H., Fisch, R., Musso, F., Lenz, B., & Rudolphi, A. (2009). *Refurbishment manual: maintenance, conversions, extensions*. Walter de Gruyter.

González, J. M. R. (2005). La experiencia domino. 21 involucró a la madera. *Boletín de información técnica [de] AITIM*, (234), 14 – 20.

Graesser, E. J., & Cozzarelli, F. A. (1991). Shape-memory alloys as new materials for aseismic isolation. *Journal of Engineering Mechanics*, *117*(11), 2590-2608.

Grecchi, M. (2008). *Il recupero delle periferie urbane: Da emergenza a risorsa strategica per la rivitalizzazione delle metropoli*. Maggioli.

Groak, S. (2002). *The idea of building: thought and action in the design and production of buildings*. Taylor & Francis.

Gruis, V., Visscher, H., & Kleinhans, R. J. (2006). *Sustainable neighbourhood transformation* (Vol. 11). IOS Press.

Guallart, V. (2004). *Sociopolis: Project for a City of the Future*. Actar.

Habraken, N. J. (1972). Supports: an alternative to mass housing. *London: architectural press (1972), 97 PP.(General)*.

Habraken, N. J. (1987). The control of complexity. *Places*, *4*(2).

Hagan, S. (2000). Cities of field: Cyberspace and urban space. *Architecture, city, environment. Proceedings of PLEA 2000*, 348-52.

Han, Y. L., Xing, D. J., Xiao, E. T., & Li, A. Q. (2005). NiTi-wire shape memory alloy dampers to simultaneously damp tension, compression, and torsion.*Journal of Vibration and Control*, *11*(8), 1067-1084.

Harris, R., & Giles, C. (2003). A mixed message: the agents and forms of international housing policy, 1945–1973. *Habitat International*, *27*(2), 167-191.

Herbert, G. (1984). The dream of the factory-made house. Walter Gropius and Konrad.

Hermelink, A., & Muller, A. (2011). Economics of deep renovation. *Berlin: Ecofys by order of Eurima – European Insulation Manufacturers Association*.

Hu, N., Feng, P., & Dai, G. (2013). The gift from nature: bio-inspired strategy for developing innovative bridges. *Journal of Bionic Engineering*, 10(4), 405-414.

Hyde, R. (2008). *Bioclimatic housing: innovative designs for warm climates*. Earthscan.

Indirli, M., Castellano, M., Clemente, P., & Martelli, A. (2001). Demo-application of shape memory alloy devices: The rehabilitation of the S. Giorgio Church bell-tower. In *Proceedings of SPIE; Smart Structures and Materials*.

Isalgue, A., Lovey, F. C., Terriault, P., Martorelli, F., Torra, R. M., & Torra, V. (2006). SMA for dampers in civil engineering. *Materials transactions*, *47*(3), 682-690.

Itard, L., & Klunder, G. (2007). Comparing environmental impacts of renovated housing stock with new construction. *Building Research & Information*, *35*(3), 252-267.

Itard, L. (2008). *Towards a Sustainable Northern European Housing Stock: Figures, Facts, and Future* (Vol. 22). Ios Press.

Jabareen, Y. R. (2006). Sustainable urban forms their typologies, models, and concepts. *Journal of planning education and research*, *26*(1), 38-52.

Janke, L., Czaderski, C., Motavalli, M., & Ruth, J. (2005). Applications of shape memory alloys in civil engineering structures—overview, limits and new ideas. *Materials and Structures*, *38*(5), 578-592.

Jaretti, S. (2008). Riflessioni sul riuso del patrimonio edilizio globale. *P. Lombardi (ed.) Riuso edilizio e rigenerazione urbana, innovazione e partecipazione, Celid, Torino*.

Jenks, M. (2000). Conclusion: the appropriateness of compact city concepts to developing countries. *Compact cities: sustainable urban forms for developing countries*, 343-350.

Jha, A. K., Miner, T. W., & Stanton-Geddes, Z. (Eds.). (2013). *Building urban resilience: Principles, tools, and practice*. World Bank Publications.

John, G., Clements-Croome, D., & Jeronimidis, G. (2005). Sustainable building solutions: a review of lessons from the natural world. *Building and environment*,*40*(3), 319-328.

Johnson, A. (1996). Rehabilitation and re-use of existing buildings. *Mills (Ed.), Building maintenance and preservation: a guide to design and management (2nd ed.), Architectural Press, Oxford*, 209-230.

Josephson, P. E., & Hammarlund, Y. (1999). The causes and costs of defects in construction: A study of seven building projects. *Automation in construction*,*8*(6), 681-687.

Kazi, A. S., & Hannus, M. (2003). Interaction mechanisms and functional needs for one-of-a-kind production in inter-enterprise settings. In *VTT SYMPOSIUM* (Vol. 224, pp. 301-312). VTT; 1999.

Keller T. (2010). Multifunctional and robust composite material structures for sustainable construction. In *Proceedings CICE 2010 – The 5th International conference on FRP composites in civil engineering*, September 27-29, Beijing, China.

Kendall, S. (2004). An Open Building Strategy for Achieving Dwelling Unit Autonomy in Multi-unit Housing. *Housing and Society*, *31*(1), 89-99.

Kendall, S. H., & Teicher, J. (2010). *Residential open building*. Routledge.

Kincaid, D. (2003). *Adapting buildings for changing uses: guidelines for change of use refurbishment*. Routledge.

Knaack, U., Klein, T., Bilow, M., & Auer, T. (2014). *Façades: principles of construction*. Birkhäuser.

Knippers, J., & Speck, T. (2012). Design and construction principles in nature and architecture. *Bioinspiration & biomimetics*, *7*(1), 015002.

Kolarevic, B. (2009). Exploring Architecture of Change. *Proceedings of the ACADIA, eds. TD Sterk, R. Loveridge and D. Pancoast*, 58-61.

Konstantinou, T. (2014). Facade Refurbishment Toolbox. Supporting the Design of Residential Energy Upgrades. PhD thesis at Delft University of Technology, Faculty of Architecture and The Build Environment, Architectural Engineering + Technology department.

Krizek, R. J., Lo, W., & Hadavi, A. (1996). Lessons learned from multiphase reconstruction project. *Journal of construction engineering and management*,*122*(1), 44-54.

Kronenburg, R. (2007). *Flexible: architecture that responds to change*. Laurence King.

Krumme, R., Hayes, J., & Sweeney, S. (1995). Structural damping with shape-memory alloys: one class of devices. In *Smart Structures & Materials' 95* (pp. 225-240). International Society for Optics and Photonics.

Kumar, P. K., & Lagoudas, D. C. (2007). Thermomechanical characterization of a TiPdNi high temperature SMA under tension. In *The 14th International Symposium on: Smart Structures and Materials & Nondestructive Evaluation and Health Monitoring* (pp. 65262E-65262E). International Society for Optics and Photonics.

Kurokawa, K. (1994). *The philosophy of symbiosis*. Academy Press.

Langston, C., Wong, F. K., Hui, E. C., & Shen, L. Y. (2008). Strategic assessment of building adaptive reuse opportunities in Hong Kong. *Building and Environment*, *43*(10), 1709-1718.

Langston, C., & Lauge-Kristensen, R. (2013). *Strategic management of built facilities*. Routledge.

Larson, K., Intille, S., McLeish, T. J., Beaudin, J., & Williams, R. E. (2004). Open source building—reinventing places of living. *BT Technology Journal*, *22*(4), 187-200.

Le Corbusier. (1931). *Towards a new architecture*. Courier Corporation.

Lepora, N. F., Verschure, P., & Prescott, T. J. (2013). The state of the art in biomimetics. *Bioinspiration & biomimetics*, *8*(1), 013001.

Lerner, J. (2014). *Urban Acupuncture*. Island Press.

Leupen, B. (2006). *Frame and generic space*. 010 Publishers.

Li, H., Mao, C. X., & Ou, J. P. (2006). Shape memory alloy-based smart buildings. *Proceedings of the 8th US*.

Lovel, J. (2013). *Building Envelopes: An Integrated Approach*. Princeton Architectural Press.

Ma, H., & Cho, C. (2008). Feasibility study on a superelastic SMA damper with re-centring capability. *Materials Science and Engineering: A*, *473*(1), 290-296.

Macdonald, S. (Ed.). (2008). *Concrete: building pathology*. John Wiley & Sons.

Magenes, G., & Calvi, G. M. (1997). In-plane seismic response of brick masonry walls. *Earthquake Engineering and Structural Dynamics*, Vol. 26, pp. 1091-1112.

Magenes, G., & Della Fontana, A. (1998). Simplified Non-Linear Seismic Analysis of Masonry Buildings. *British Masonry Society*, Vol. 8, pp. 190-195.

Magenes, G. (2000). A method for pushover analysis in seismic assessment of masonry buildings. In *Proceedings of the12th world conference on earthquake engineering*.

Magenes, G., & Morandi, P. (2006). La progettazione sismica degli edifici in muratura. *Costruire in Laterizio*, *110*, 60-65.

Mainstone, R. J. (1971). Summary of paper 7360. On the stiffness and strengths of infilled frames. In *ICE Proceedings* (Vol. 49, No. 2, p. 230). Thomas Telford.

Mann, W., & Muller, H. (1988). Interpretation of experimental results with an enlarged failure criterion considering the stressed in the head joints. Technische Hochschule.

Martelli, A. (2006). Modern seismic protection systems for civil and industrial structures. *An advanced approach to earthquake risk scenarios, with applications to different European towns*.

Mazzolani, F. M., & Mandara, A. (2002). Modern trends in the use of special metals for the improvement of historical and monumental structures. *Engineering Structures*, *24*(7), 843-856.

McCleary, P. (1983). An Interpretation of Technology. *Journal of Architectural Education*, *37*(2), 2-4.

McCleary, P. (1984). History of technology. *Architectural research. New York: Van Nostrand Reinhold Company*.

McDonough, W., & Braungart, M. (2010). *Cradle to cradle: Remaking the way we make things*. MacMillan.

McKim, R., Hegazy, T., & Attalla, M. (2000). Project performance control in reconstruction projects. *Journal of Construction Engineering and Management*,*126*(2), 137-141.

McLaren, D. (1992). Compact or dispersed? Dilution is no solution. *Built Environment (1978-)*, 268-284.

Mehta, M., Scarborough, W., & Armpriest, D. (2008). *Building construction: Principles, materials, and systems*. Pearson Prentice Hall.

Meijs, M., & Knaack, U. (2009). *Components and connections: principles of construction*. Walter de Gruyter.

Mengüşoğlu, N., & Boyacioğlu, E. (2013). Reuse of industrial built heritage for residential purposes in Manchester (1). *METU JFA*, *1*, 117.

Mezzetti, P., Megnano, S., & Zajczyk, F. (2003). Large scale and Housing Estates in Italy. Overview of developments and problems in Milan. *RESTATE Report2d*. A-D Druk bv, Utrecht.

Minguet, J. M., & Vazquez, O. M. (2009). Bioclimatic Architecture: Instituto Monsa de Ediciones, S.A.

Mitropoulos, P., & Howell, G. A. (2002). Renovation projects: Design process problems and improvement mechanisms. *Journal of Management in Engineering*, *18*(4), 179-185.

Moe, K., & Smith, R. E. (2012). *Building Systems: Design, Technology, and Society*. Routledge.

Morandi, P., Hak, S., & Magenes, G. (2011). Comportamento sismico delle tamponature in laterizio in telai in ca: definizione dei livelli prestazionali e calibrazione di un modello numerico. *Atti del XIV convegno nazionale ANIDIS*.

Motahari, S. A., Ghassemieh, M., & Abolmaali, S. A. (2007). Implementation of shape memory alloy dampers for passive control of structures subjected to seismic excitations. *Journal of Constructional Steel Research*, *63*(12), 1570-1579.

Munari, M., da Porto, F., Bartolozzi, A., Mocellini, M., Valdesolo, A., & Modena, C. (2011). Analisi di vulnerabilità sismica e interventi di miglioramento strutturale di un aggregato nel centro storico di L'Aquila.

Murie, A., Knorr-Siedow, T., & Van Kempen, R. (2003). *Large housing estates in Europe: general developments and theoretical backgrounds*. Utrecht University. Faculty of Geosciences. Urban and Regional Research Centre.

Nasar, J. L. (1992). *Environmental aesthetics. Theory, research and applications*. Cambridge University Press.

Nemry, F., Uihlein, A., Colodel, C. M., Wetzel, C., Braune, A., Wittstock, B., ... & Frech, Y. (2010). Options to reduce the environmental impacts of residential buildings in the European Union—Potential and costs. *Energy and Buildings*,*42*(7), 976-984.

Nuti, C., & Vanzi, I. (2003). To retrofit or not to retrofit?. *Engineering structures*,*25*(6), 701-711.

Olgyay, V., & Olgyay, A. (1963). Design with climate: bioclimatic approach to architectural regionalism: Some chapters based on cooperative research with Aladar Olgyay. Princeton University Press.

Olgyay, V., & Seruto, C. (2010). Whole-building retrofits: A gateway to climate stabilization. *ASHRAE Transactions*, *116*(2), 1-8.

Otani, S., Hiraishi, H., Midorikawa, M., Teshigawara, M., Fujitani, H., & Saito, T. (2000). Development of smart systems for building structures. In *SPIE's 7th Annual International Symposium on Smart Structures and Materials* (pp. 2-9). International Society for Optics and Photonics.

Ouwehand, A., & van Daalen, G. (2002). *Dutch housing associations. A model for social housing*. Delft University Press.

Ozbulut, O. E., Hurlebaus, S., & DesRoches, R. (2011). Seismic response control using shape memory alloys: a review. *Journal of Intelligent Material Systems and Structures*, 1045389X11411220.

Panagiotakos, T. B., & Fardis, M. N. (1996). Seismic response of infilled RC frames structures. In *11th World Conference on Earthquake Engineering, Acapulco*.

Pant, A. (2013). Cohousing – a model for Camphill? Scottish Neighbourhood Meeting September 2013.

Parsons, A. (2007). *Small scale, BIG CHANGE: Urban Acupuncture as a strategy for sustainable regeneration*. Portsmouth University of Portsmouth.

Pascaris, J. (2012). *Healing Neighbourhoods through Urban Acupuncture*. Ryerson University.

Pawlyin, M. (2011). *Biomimicry in architecture*. London: RIBA publishing.

Petrovski, J. T. (2004). Criteria for seismic risk reduction of earthquake resistant buildings. 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada August 1-6, 2004 Paper No. 1554.

Pink, S. (2004). *Home truths: Gender, domestic objects and everyday life*. Berg.

Power, A. (1997). *Estates on the Edge. The Social Consequences of Mass Housing in Northern Europe*. Macmillan.

Power, A. (2008). Does demolition or refurbishment of old and inefficient homes help to increase our environmental, social and economic viability?. *Energy Policy*, *36*(12), 4487-4501.

Pozzo, A. M. (2005). Federcasa, I numeri della casa. Unpublished report for Federcasa.

Prak, N. L., & Priemus, H. (1986). A model for the analysis of the decline of postwar housing. *International Journal of Urban and Regional Research*, *10*(1), 1-7.

Preservation Green Lab. (2011). The Greenest Building: Quantifying the Environmental Value of Building Reuse. *National Trust for Historic Preservation*.

Priemus, H. (1986). Post-war public high-rise housing estates: what went wrong with housing policy, with the design and with management?. *Journal of Housing and the Built Environment*, *1*(2), 157-185.

Priemus, H. (1989). Upgrading of large-scale housing estates in The Netherlands. *Journal of Housing and the Built Environment*, *4*(2), 145-160.

Priemus, H. (2005). *Decay of large housing estates revisited*. In van Kempen, R., Cernic Mali, B., (eds.). Restructuring large housing estates in Europe: policies, practices and perspectives. Urban Planning Institute of the Republic of Slovenia, Ljubljana.

Quah, L. K., Van den Brand, G. J., & Di Giulio, R. (2004). Process innovation for design and delivery of IFD buildings.

Rabeneck, A., Sheppard, D., & Town, P. (1973). Housing flexibility?.*Architectural Design*, *43*(11), 698-727.

Reap, J., Baumeister, D. & Bras, B. (2005). Holism, Biomimicry and Sustainable Engineering. In *ASME International Mechanical Engineering Conference and Exposition*. Orlando, FL, USA.

Ren, W., Li, H., & Song, G. (2008). An innovative shape memory alloy damper for passive control of structures subjected to seismic excitations. In *Proceeding of the 14th World Conference on Earthquake Engineering* October 12-17, Beijing, China

Ridder, H. D., & Vrijhoef, R. (2006). From demand-driven supply towards supply-driven demand in construction: a “living building” experiment. In W. Hughes (Ed.), *Proceedings 3rd International SCRI symposium* (pp. 530-542).

Rodrigues, M. F., & Teixeira, J. M. C. (2006). Building pathologies in social housing: the portuguese state of the art.

Rogers, R. (1997). *Cities for a small Planet*.

Rossi, A. (1978). *L’architettura della città*. Città studi editore.

Ruby, A. (2005). Reprogramming architecture. *VOLUME*, *2*, 05.

Russell, S. R. (2008). Metabolism Revisited Prefabrication and Modularity in 21st Century Urbanism.

Sabatino, R., & Rizzano, G. (2010). Non-linear Static Analysis of Masonry Structures. Simplified Equivalent Frames and accurate models. In *Proc. of 14th European Conference on Earthquake Engineering*.

Sanvido, V. E. (1991). *Managing retrofit projects* (Doctoral dissertation, University Park, PA 16802 Georgia).

Sargisson, L. (2010). Cohousing: a utopian property alternative?. *Centre for the Study of Social and Global Justice. Retrieved February*, *20*, 2013

Schilling, J. M. (2002). Vacant Properties: Revitalization Strategies. ICMA.

Schneider, T., & Till, J. (2005). Flexible housing: opportunities and limits.*Architectural Research Quarterly*, *9*(02), 157-166.

Scuderi, G. (2015). Adaptive building exoskeletons: A biomimetic model for the rehabilitation of social housing. *International Journal of Architectural Research: ArchNet-IJAR*, *9*(1), 134-143.

Shami, M., & Kanafani, A. (1997). Coping with construction in operational airports: SFIA case study. *Journal of transportation engineering*, *123*(6), 417-428.

Shidan, C., & Qian, S. (2011). Notice of Retraction “Urban Acupuncture” strategy in the Urban Renewal. In *Electric Technology and Civil Engineering (ICETCE), 2011 International Conference on* (pp. 1859-1862). IEEE.

Simpson, J. A., Melton, K., & Duerig, T. (1986). *U.S. Patent No. 4,631,094*. Washington, DC: U.S. Patent and Trademark Office.

Smith, B. S., & Carter, C. (1969). A method of analysis for infilled frames. In *ICE Proceedings* (Vol. 44, No. 1, pp. 31-48). Thomas Telford.

Sousa Cruz Da, P. J. (2013). *Structures and Architecture: New concepts, applications and challenges*. CRC Press Book.

Stamps, A. E. (1999). Physical determinants of preferences for residential facades. *Environment and Behavior*, *31*(6), 723-751.

Song, G., Ma, N., & Li, H. N. (2006). Applications of shape memory alloys in civil structures. *Engineering Structures*, *28*(9), 1266-1274.

Stevens, C. M., & Wheeler, K. E. (2008). Implementing earthquake prone building policy under the Building Act 2004—Wellington City’s approach. In *Proceedings of the New Zealand Society for Earthquake Engineering,‘Engineering an Earthquake Resilient New Zealand’(NZSEE) Conference, Wairakei, New Zealand* (pp. 11-13).

Tenner, A. R., & DeToro, I. J. (2008). Garvin's Eight Dimensions of Product Quality. In: *Total Quality Management*. Addison-Wesley Pub (Sd).

Thermou, G. E., & Elnashai, A. S. (2006). Seismic retrofit schemes for RC structures and local-global consequences. *Progress in Structural Engineering and Materials*, *8*(1), 1-15.

Thomsen, A. F., & van der Flier, C. L. (2008). *Replacement or reuse? The choice between demolition and life cycle extension from a sustainable viewpoint. Shrinking Cities, Sprawling Suburbs, Changing Countrysides* (Vol. 1). Centre for Housing Research, UCD.

Thomsen, A. (2011). A paradigm shift or chocke? The future of western Europe housing stocks. In *Management and Innovation for a Sustainable Built Environment MISBE 2011, Amsterdam, The Netherlands, June 20-23, 2011*. CIB, Working Commissions W55, W65, W89, W112; ENHR and AESP.

Thuesen, C. L., & Claeson, C. C. (2009). The Long Tail and Innovation of New Construction Practices: Learning Points from Two Case Studies. *Open Building Manufacturing Key Technologies, Applications, and Industrial Cases*, 49-64.

Tierney, K. (2005). Effective Strategies for Hazard Assessment and Loss Reduction: The Importance of Multidisciplinary and Interdisciplinary Approaches(Report from Internet). *Natural Hazards Research and Applications Information Center, Institute of Behavioral Science, University of Colorado, Boulder, CO.*

Till, J., & Schneider, T. (2005). Flexible housing: the means to the end.*Architectural Research Quarterly*, *9*(3-4), 287-296.

Torra, V., Isalgué, A., Lovey, F. C., & Martorelli, F. (2007). Phase metastability in shape memory alloys. Dampers in engineering via SMAs. In *Proceedings-Estonian academy of sciences physics mathematics* (Vol. 56, No. 2, p. 177). Estonian Academy Publishers; 1999.

Tosi, A., & Cremaschi, M. (2001). *Housing policies in Italy*. Vienna: Interdisciplinary Centre for Comparative Research in the Social Sciences (ICCR).

Turkington, R., Van Kempen, R., & Wassenberg, F. (2004). High-rise housing in Europe: Current trends and future prospects. Delft: DUP Science.

Turnšek, V., & Sheppard, P. (1980). *The shear and flexural resistance of masonry walls*.

University of Bath. 2008. *Biomimetics: Copying ideas from nature into engineering*. Bath: University of Bath.

UNI 8289:1981_ Edilizia. Esigenze dell'utenza finale. Classificazione.

van Beckhoven, E., Bolt, G., & van Kempen, R. (2005). Theories of neighbourhood change and neighbourhood decline: Their significance for post-WWII large housing estates. *Příspěvek přednesený na konferenci Housing in Europe: New Challenges and Innovations in Tomorrow's Cities. Reykjavik*,*29*(6), 2.

van der Flier, C. L., & Thomsen, A. F. (2006). Life cycle of dwellings: analysis and assessment of demolition by Dutch housing associations. In *International Conference ENHR, Ljubljana, Slovenia, 2-5 July 2006; Workshop 7, Physical Aspects of Design and Regeneration*. Urban Planning Institute of the Republic of Slovenia.

Van Kempen, R. V., Murie, A., Tosics, I., & Knorr-Siedow, T. (2006). Regenerating large housing estates in Europe: a guide to better practice. *Zeist: AD Druk bv*.

Van Lievenoogen, M. J. (2011). *Public space for livable neighbourhoods: How generic spatial interventions can realize conditions for the development of public space to accomplish a dureable living environment in specific urban living areas* (Doctoral dissertation, TU Delft, Delft University of Technology).

van Nederveen, S., Gielingh, W., & de Ridder, H. (2009). Value-Oriented Industrial Building for a Sustainable Future. *Open Building Manufacturing*, ManuBuild.

Vargas, B. (2007). Industrialización de la construcción para la vivienda social. *Revista Nodo*, *2*(3).

Verbeeck, G., & Cornelis, A. (2011). Renovation versus demolition of old dwellings: comparative analysis of costs, energy consumption and environmental impact. Paper presented at the PLEA 2011: Architecture & Sustainable Development, Louvain-la-Neuve, Belgium.

Vincent, J. F. (2006). Applications—influence of biology on engineering. *Journal of Bionic Engineering*, *3*(3), 161-177.

Waide, P., Guertler, P., & Smith, W. (2006). High-rise refurbishment: The energy-efficient upgrade of multi-story residences in the European Union.*International Energy Agency*.

Wassenberg, F. (2004). Renewing stigmatised estates in the Netherlands: A framework for image renewal strategies. *Journal of Housing and the Built environment*, *19*(3), 271-292.

Wassenberg, F. (2012). Housing Estates. In J. S. Editor-in-Chief: Susan (Ed.), International Encyclopedia of Housing and Home. Elsevier.

Weeks, J. (1963). Indeterminate architecture. *Transactions of the Bartlett Society*, *2*, 85-106.

Wilde, K., Gardoni, P., & Fujino, Y. (2000). Base isolation system with shape memory alloy device for elevated highway bridges. *Engineering structures*,*22*(3), 222-229.

Williams, K. (2000). Does intensifying cities make them more sustainable. *Achieving sustainable urban form*, 30-45.

Williams, K., Jenks, M., & Burton, E. (2000). *Achieving sustainable urban form*. Taylor & Francis.

Wilson, J. Q., & Kelling, G. L. (1989). Making neighborhoods safe. *Atlantic Monthly*, *263*(2), 46-52.

Zambelli, E. (2004). *Ristrutturazione e trasformazione del costruito*. «Il Sole 24 Ore».

Zhu, S., & Zhang, Y. (2007). Seismic behaviour of self-centring braced frame buildings with reusable hysteretic damping brace. *Earthquake engineering & structural dynamics*, *36*(10), 1329-1346.

Zillmann, K. (2000). Rethinking the compact city: Informal urban development in Caracas. *Compact Cities: Sustainable Urban Forms for Developing Countries*, 193-206.

12. LIST OF TABLES

13. LIST OF FIGURES

14. ABOUT THE AUTHOR

In 2012, Giuliana Scuderi graduates with merit from the Master's course in architectural engineering of the University of Brescia (Italy) with the thesis *Rethinking urban connections of Civita di Bagnoregio*.
In the same year, she undertakes a stage at the engineering company Weproject srl and she awards a Doctoral fellowship at the University of Trento (Italy) in the School of Engineering of civil and mechanical structural systems (28° cycle). During the three years of doctorate, she is visiting researcher for twelve months at the Eindhoven University of Technology (Netherlands).
Her research focuses on the integrated retrofit of the existing heritage, using innovative techniques and technologies, with a particular attention on seismic engineering aspects.
Since the 2013, she works as teaching assistant, mentor, tutor, and visiting lecturer at the University of Brescia (Italy).
From November 2015, Giuliana Scuderi works as freelancer editor of scientific papers focusing on civil engineering and as freelancer writer of architectural articles for online journals.
In 2016, she is appointed Lecturer of Civil engineering at the HZ University of Applied Science in Vlissingen (Netherlands).

Some of her publications are listed below:

Scuderi, G. and Teuffel, P., Shape memory alloys for seismic retrofitting of social housing in an integrate perspective, Proceedings SMAR 2015, Third conference on smart monitoring, assessment and rehabilitation of civil structures, Antalya, Turkey, 7-9 September 2015.

Scuderi G., Adaptive building exoskeletons. A biomimetic model for the rehabilitation of social housing, in: "Archnet-IJAR", Volume 9, Issue 1, March 2015, pp. 134-143

Scuderi, G. and Teuffel, P., Building Exoskeletons for Seismic Retrofitting, World Academy of Science, Engineering and Technology, International Science Index, Architectural and Environmental Engineering, 2014, 1(4), 195.

Scuderi G., Sistemi metallici, filtro per gli involucri edilizi. Traguardi e sperimentazioni del XX secolo, in: « Le jeu savant », Luce e oscurità nell'architettura del XX secolo - Light and Darkness in 20th Century Architecture, convegno internazionale nell'ambito del progetto di ricerca Da Ravenna a Vals, 2014.

Scuderi G., Racconti privati nella città pubblica, in Lambertini A., Metta A., Olivetti M. L. (curated by), "Città pubblica/Paesaggi comuni. Materiali per il progetto degli spazi aperti dei quartieri ERP", p. 231-233, Gangemi Editore, Roma 2013.

Scuderi G. et al., Riqualificazione e riuso del complesso la Santissima di Gussago (Bs), in Marucci G.(curated by), “Costruire nel costruito. Architettura a volume zero”, Architettura e città n. 7/2012, Di Baio Editore, Milano 2012.

Scuderi G. et al., Occasioni di conoscenze, in Di Resta S. Giani E. (curated by), “La Rinascenza di Civita”, IUAV: 108, p.14-15, Grafiche Veneziane, Venezia 2011.

Scuderi G., Zanotti S., Progetto di riqualificazione di un’area industriale dismessa, in Angi B. (curated by), “Attraverso il progetto”, p. 90-91, Officina Edizioni, Roma 2010.

Scuderi G., Zanotti S., Progetto di una casa di emergenza, in Botti M. (curated by), “Case di emergenza”, p. 130-133, Aracne editrice, Roma 2010.