RFCS research project

Renovation Of Buildings Using Steel Technologies

ROBUST **Contract n° RFSR-CT-2007-00043**

Work Package n°3

Steel-intensive technologies for building extensions and conversions

3.4 – design guidance

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DESIGN GUIDANCE FOR EXTENSIONS

TABLE OF CONTENTS

Each year across Europe, the construction of new buildings is represented about 1 % to 2% of all the existing. It means that a large market share (50 % in France, for example) is devoted to refurbishment.
The restoration of an old building (structure, facades, energy systems) requires good professional skills because it is necessary to take into account numerous constraints: technique, regulations, economy, specificities of the site and from now on environment.

To approach a project of rehabilitation with steel solutions is the first intention of this design guidance's proposal.

1 Vertical extension: a way of renovation

Steel technologies may be combined with all other materials and products and offer free shapes and colours.

Residential building in Rotterdam

civil eng. Faculty in Rzeszow (PL), Roof-top extensions

1.1 Definitions of different ways of refurbishment

For the majority of projects, refurbishment consists in keeping an essential part of a work (frame, main façade, etc) while modifying another one, more or less deeply. Thus, this term can cover various types of work on the building, from the most superficial to the most extensive:

Renovation : It can involve an improvement of the comfort, the aesthetics or the safety, due to a standard or not. The works are rather light and sometimes allow to the occupants to stay on site during the construction period.

Re-structuring : means recomposing the volumes, reorganizing the functions in the building. We can then remove levels, strengthen some parts but also create new floors: extensions or roof-top additions.

Reconstruction: with the preservation of facades, it means keeping only the envelope or the global volume in order to rebuild everything else.

1.2 Objective and drivers

Up to now, the reasons for the choice of refurbishment are various. Mostly they were cultural, technical or related to the site or standards, even if the economical aspects are kept in mind.
From several years, a new approach is considered in one hand the global need for new areas – especially for residential and offices – and in other hand the unavailability of land spaces in city centres.
Basically, the reasons that lead developers or designers to consider a retrofit operation are as follow:

- When a building has to change of use, by converting offices in residential accommodations for example, structural data and conditions of load are modified. In the same time, other standards (thermal efficiency, fire safety, health) are involved and all the building has to be upgraded to current requirements.
- When a building has to be upgraded to current standards (thermal efficiency, fire safety, health, etc), it is often because the objective is to change of use, by converting offices in residential accommodations. Modifying structural data
- When one wishes to retain the existing surface area and volumes, the refurbishment is the way which allows keeping the original dimensions. Indeed, the urban planning regulations do not still authorize to reconstruct in the identical.
- When the situation of the building will present inconveniences in demolition stage. Very technical, this part of the works can raise problems of vibration towards the nearby buildings. The environment is also determining for the safety, the evacuation of wastes and noise.
- When a building is classed as a historic monument, refurbishment is often the only option. Sometimes to find the original state, it is necessary to lead a detailed historic research (original plans or sketches) and same to redo objects with former techniques: moulds for cast-iron parts. As an architectural masterpiece, the preservation of the great heritage value is also an advantage for its business concern: rent or sale.

The set leads to the choice of refurbishment. Before the decision, the conclusion of the assessment is about profitability, feasibility and viability of the project.

Drivers for Renovation or Rehabilitation	MAIN CRITERIA	Related to a standard or regulation
Keep the original or improve it (partly or not	Aesthetics / Thermal / Fire	Structural and Thermal
More efficient use of land	Economic, structural and sustainability	Urban planning
Change of use (building)	Economic	All (but not directly)
Energy efficiency	Energy and economic	Thermal regulation
Upgrade to new regulations	Energy / Fire Safety	Thermal / fire safety regulation
Governments funding programs to meet Kyoto targets	Climate change	Sustainable aspects

Conservation of national heritage register	Aesthetics	All (but not directly)
Deterioration	Health and safety	Health and/or safety

Table 1.1: Drivers for renovation project

Considering the wide periods of history of construction, it is possible to summarize the main situations:
1 - A concrete building, erected after the second world war, situated in a cheap suburb = it is cheaper and faster to destroy and build a new one.
2 –A building of the 20s, placed in town centre, is more interesting to rehabilitate.
3 – A building of the 60s (or 70s) in town centre, but when it is necessary to put in accordance with of many regulations = it is a dilemma.

2 Review of existing building European context

A study included in Robust project was carried out to collect average information for European countries, dealing with the characteristics of the existing multi-storey building and main regulations (structural design, thermal regulation, fire safety, etc).
At the end, the 'average European' is a 4-6 storey building made by concrete or masonry.
From the beginning of design stages, a series of key-points of the construction are determining towards the requirements. Some of those items are presented in chapter 3.

An overview of European office market concerning economical elements contains those typical values: rental value, prime rents, vacancy, etc. Information of those big cities were essentially collected from reports made by main real estate companies of this sector.

OFFICE MARKET - Overview		Stock	Availability	Vacancy rate	Take-up (sq.m)	
Q3 - 2009		m sq.m	m sq.m		Q3 - 2009	Total 2009
LONDON	**Central London**	**277.36**	**19.97**	**7.20%**	**2700000**	**5500000**
	West End	112.84	7.56	6.70%	1490000	
	City	92.50	8.14	8.80%	850000	
BRUSSELS	**CBD**	12.87	**1.39**	**10.80%**		
BERLIN	Prime Rent	17.5	1.66	9.40%	295000	
PARIS	CBD	5.40	0.27	5.00%		
	total of Paris	12.92	0.62	4.80%		
	La Défense	3.00	0.12	4.00%		
	Total Region	42.31	2.75	6.50%		

CBRE Marketview - 2009

Table 2.1: Extract of office market values

Across Europe, an important point is that refurbishment and second hand are representing 60 % of the global office market. Rental prices in city centre (2009 values) are beginning at 220 €/m²/year and can reach 650 or 1000 €/m²/year in central business districts.

3 Sequence of pre-design stages

3.1 The diagnosis survey

The diagnosis is the first stage of a project of refurbishment, essential in its success. The examination is complete and accurate to determine the existing conditions and the process to implement.
A general description of the building should be available via information regarding the age of construction, the architect, architectural and technical drawings and when is available the report of the structural calculation.
The investigation of the foundation is one of the prime tasks and a detailed and deep visual inspection of the actual state of the foundation is recommended, including the geotechnical capacity of the ground. The second step is to analyze the actual status of the existing bearing structure: walls, beams, columns, panels

In the case of buildings made of steel, the nature and the characteristics of the materials must be identified for each element: cast iron, puddle iron or steel. A particular attention will be brought to the treatment of protection against the corrosion: the former (sometimes to remove) and the new.
One of steel's advantages is that the structure is often reachable, what facilitates the diagnosis.

3.2 The architectural concept

Aspects related to the cultural heritage and roof shapes are probably the first criteria which are oriented the concept choice for the designers.
The shape will in fact heavily influence the capacity to sell new areas and to rent the new floor by the investor.

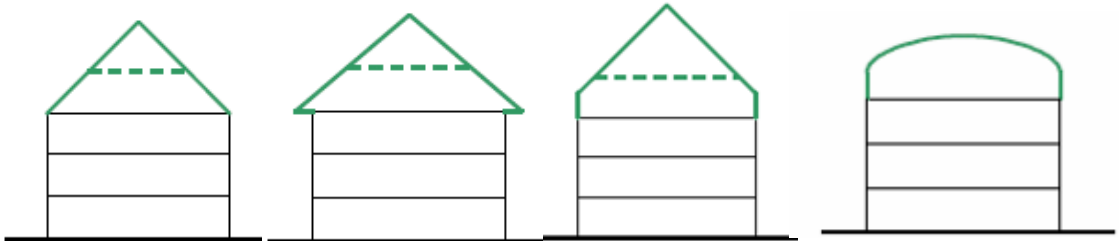


Fig. 3.1: schemes for generic shapes

Once this principle was determined, the designers have to study deeply the technical aspects of the operation, both for a good conception and for a feasibility of the execution on the site.

3.3 Recall of essential requirements

In this chapter, all of the 6 essential requirements shall be summarized. The following proposal is just dealing with the both first ones requirements in the form of "question answer".

The products must be suitable for construction works which (as a whole and in their separate parts) are fit for their intended use, account being taken of economy, and in this connection satisfy the following essential requirements where the works are subject to regulations containing such requirements. Such requirements must, subject to normal maintenance, be satisfied for an economically reasonable working life. The requirements generally concern actions which are foreseeable.

Mechanical resistance and stability: The construction works must be designed and built in such a way that the loadings that are liable to act on it during its constructions and use will not lead to collapse (of the whole or part of work), major deformations, damage to other parts due to major deformations as well as to an event disproportionate to the original cause.
A preliminary calculation should be made actually taking into account the elimination of the existing roof and the replacement with a light weight steel structure. Different bearing structure will require different technical details and connection solutions between existing and new elements.
The previous diagnosis provide information concerning existing elements and the next figure shows, like a tool, how those information can be used with the objective of structural requirement to obtain compatible steel solutions.
The pre-design considerations are dealing with the characteristics of support (results of diagnosis, dimensions, concrete grade,...) and the adapted specifications of the considered requirement.

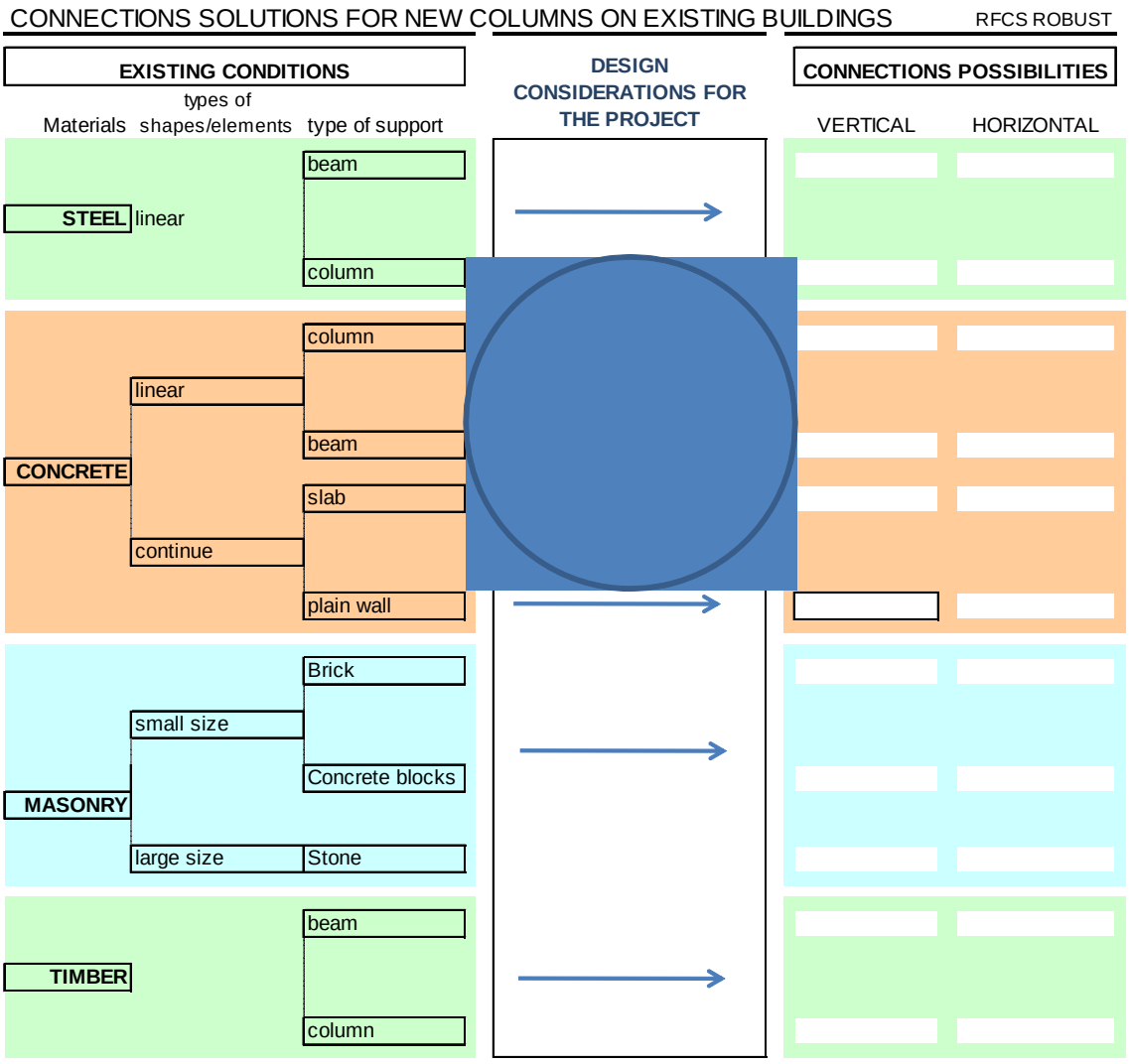


Table 3.2: Analysis for connection solutions

Safety in case of fire: The construction works must be designed and built in such a way that in the event of an outbreak of fire, the load-bearing capacity of the construction can be assumed for a specific period of time, the generation and spread of fire and smoke within the works and to neighbouring construction are limited, occupants can leave the works or be rescued by other means and the safety of rescue teams is taken into consideration.

The criteria of the applicable requirement must be obviously considered, in particular the global height, the number of levels and the means of escape.
The performances of the existing works can be insufficient after the vertical extension. In that case, compliance works are to be planned, what can be heavy and expensive.

The other essential requirements to be developed are:

- Hygiene, health and the environment,
- Safety in use,
- Protection against noise,
- energy economy and heat retention.

3.4 Economical and sustainable elements

Economical aspect

According to the definition of sustainability, economical aspects must be considered as environmental and social for any project. During the study of feasibility, the comparison must be led between on one hand the version with dismantling and new building and on the other hand the improvement of existing with an extension.

Of course, the biggest difficulty is to obtain relevant values for life cycle assessment, including maintenance and use of building, while mostly the client is not the final manager or user of the building. Nevertheless, the calculation on the design and construction stages already shows the interest of this type of approaches, especially in city centres. Among advantages, some have an evident economic consequence, as follows:

- Speed of construction = fewer labour costs and reduction of inconvenience on site,
- Faster delivery = fewer interest charges
- Part dismantling = waste reduction and linked costs
- Landfill optimization = reduction of urban sprawl,
- Improvement of thermal aspects = upgrade of energy-efficiency and energy cost reduction.

A case study, in Robust project was developed considering an existing 'average 4-storey building' and the aim of this virtual project is to create a 6-storey building with a good thermal behaviour, in Paris. A new building after dismantling the existing was compared to a retrofitting solution including a vertical extension.

The return on investment calculation took into account construction and dismantling costs as well rental values and global energy consumption: even for the worst combination, the extended building is more efficient (for the investor) until ten years after!

	Operating costs		Balance including Rental income vs Energy expenditure			Results after **X** years
Worst comparison	(demolition, improvement)		**2**	**3**	**5**	**10**
Reference (4-storey concrete)	0	No works	1 055 700.00 €	1 583 550.00 €	2 639 250.00 €	5 278 500.00 €
NEW BUILDING + Demolition	2 080 800.00 €	lowest	-471 546.00 €	333 081.00 €	1 942 335.00 €	5 965 470.00 €
STEEL extension + thermal	1 723 880.00 €	highest	-123 622.40 €	676 506.40 €	2 276 764.00 €	6 277 408.00 €

Table 3.3: Return on investment comparison

Sustainable approach

Vertical extensions are of course a way of optimizing the landfill, which is efficient from the sustainable point of view. All the projects of renovation are also an opportunity to improve the quality of the building. But environmental aspects are also dealing with environmental product declarations, impacts on construction site or low energy and carbon solutions.

An assessment has been carried out to shows the compatibility of a BREEAM or HQE program on a vertical extension. There is important equivalence between both methods of environmental quality process as they deal with the same main concerns during the life-span of the building, starting from the stage of planning organization during the phase of architectural conception until the demolition and the waste management. However, the study has enlighten the fact that the definition of the criteria's being different, the HQE system would be more easily attainable as it's lacking clarity in the requirements.

Moreover it contains much more "site specific" credits which cannot be achieved on all projects, 17% of the BREEAM credits are impacted by the nature of the extension project while this proportion represents 36% of the HQE credits.

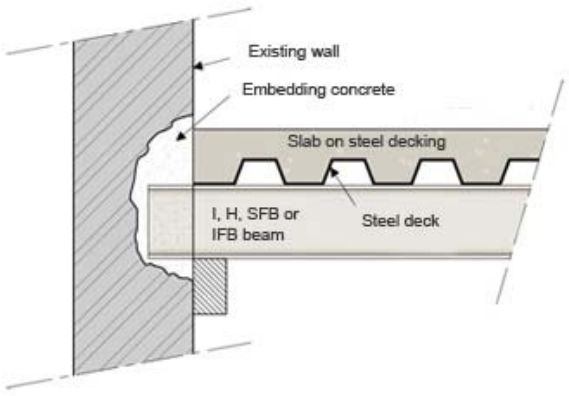
4 Generic techniques of renovation with steel

This chapter will present the main aspects of renovation and the different techniques by parts of works that the operation needs to realize.
At first the generic techniques for fastening on the existing construction are to be evoked by showing the main uses: structure and envelope.
Concerning structural elements, different cases have to be developed. Each of them will be presented by indicating capacities of products and their specific uses (from low to heavy loads for example), as well as a brief description of their implementation. The sound structures of an existing large structure can sometimes be retained and used for a new application provided they are compatible with the new load distribution in the modified structure. The materials of the supporting elements to be considered could be timber, concrete or masonry, even steel.

Beams installation

The fastening of steel beams to masonry or concrete walls is a common practice, but the success of this operation is influenced by the nature of the loads to be transmitted to the supporting point as well as by the inherent strength of the supporting wall.

steel beam connected to masonry wall



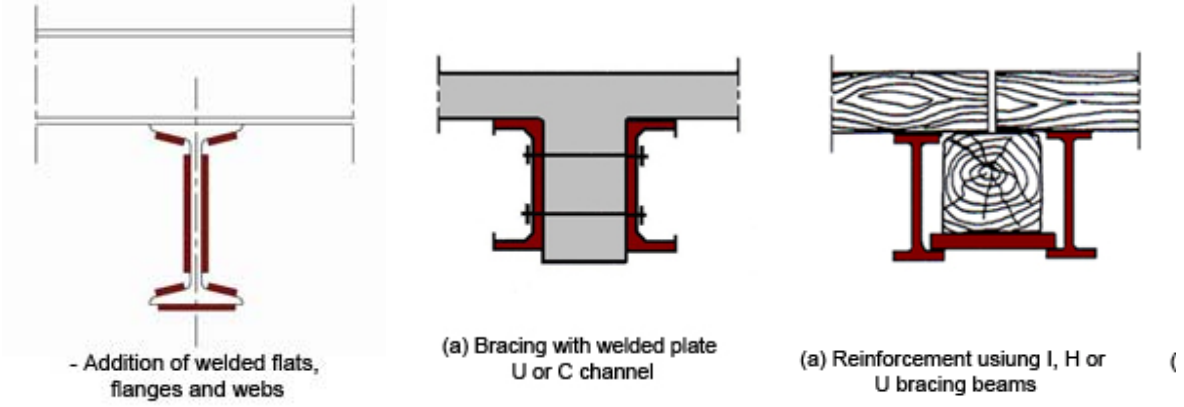
Details of fixing a steel beam into a recess

With a support made of concrete, the cutting must not damage the steel reinforcing bars. A break in the reinforcing steel is particularly detrimental when this has to resist bending stresses. When carrying out operations of this type on a structure, joints inducing embedment effects must be treated with great precaution. When such loadings have not been taken into consideration, they are detrimental to the operation of the structure and when they are sought they are nonetheless difficult to really bring into play.

Reinforcement of beams and columns

Some projects do not allow putting off the totality of the existing construction. The reinforcement of elements of the structure is then essential. It is possible to strengthen the existing beams by adding mostly steel flat bars which increase the loading capacities.

The difficulty is that, in certain cases, such as earthquake-resistant design, unwise addition of material can result in the weakening of the global structure.



steel beams *concrete beam* *wooden beam*

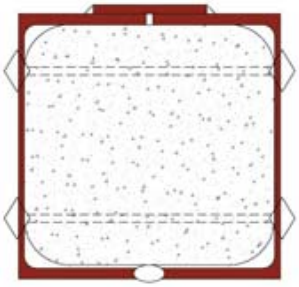
Different cases of beams reinforcement by addition of steel components

In general, reinforcement of beams could be apply to all current materials; the reason is mostly structural as improvement of inertia or lack of rigidity.

The column to be reinforced could be in steel or cast iron as well as in concrete. As in the case of beams, the general principle remains to add flats which will increase the inertia and the compressive strength.
The reinforcement of a metal column may be necessary when there is serious corrosion, but it is most often performed when there is a marked increase in loadings or, following structural modifications, an increase in the slenderness ratio.

Steel columns consisting of I and H sections, tubular sections and sometimes solid sections are greatly esteemed in refurbishment work as (temporary or permanent) additional supports for stone or reinforced concrete structures. The bases of these supporting columns are generally articulated in order not to transmit interference moments to the slab. In all cases, it is advisable to verify the slab's resistance to penetration and where necessary to distribute the load or to provide for a foundation block.

Cast iron column beneath timber beam

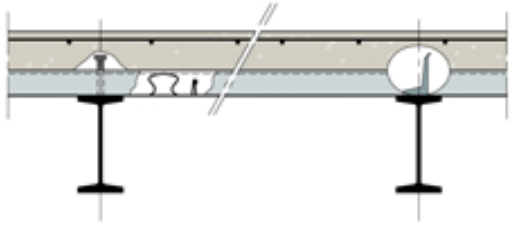


Example of reinforcement of concrete columns

Slabs

In this case, it can involve of strengthening or of modifying the existing floors.
A transformation of any building motivated or by the change of use (increase of operating loads) or simply by the outdated state often requires to deposit the former slab (floor by floor).

The change of use raises the problem of the acceptable load of the construction and of its structural completeness and the total reconstruction of these floors is still easy because girders confidentially connected to the existing constitute elements of stability of the construction.

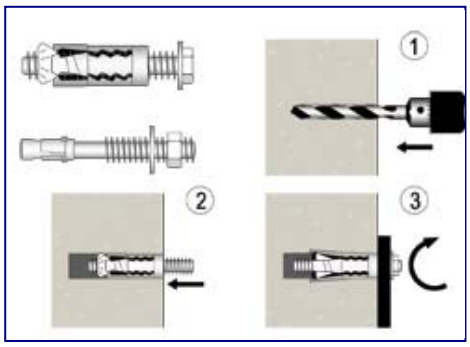


Section on existing steel beams

Steel decking and old timber beams

Connection systems

available complementary products for fastening steel elements to existing structures of steel, concrete, brick and timber : expansion bolts and anchor studs, chemical bolts



everyone will be presented by indicating capacities of products and their specific uses (from low to heavy loads for example), as well as a brief description of their implementation.

Other general techniques for refurbishment

The trends of building market and sustainable aspects could boost refurbishment activities.
A wide and illustrated presentation of main techniques for refurbishment using steel products could be useful to provide alternative solutions for clients and designers.

Especially for extensions projects, the existing situation may require to manage a case such as the creation of aperture, the installation of a new element, the removal of existing column or even some corrosion aspects.

5 Steel technologies available

Actually, all steel products could be used in a refurbishment project: to create a complementary frame as well to renew the building envelop.
Whatever is the building process, products are made off-site, transported easily for a fast erection on the construction site: an adapted solution to all the scenarios.

Hot-rolled sections

A large range of sections, widely available products, flexibility of transformation (but accuracy) are the known characteristics.
The implementation is possible on all the types of existing materials, offering an optimization of every project.

Light gauge steel profiles

Light steel framing is an ideal structural solution for over-roofing because it reduces the loading on the existing building. Different steel technologies may be used to obtain a suitable solution for each project.
New floors can be installed as light steel panels or as individual joists generally supported by additional beams connected to discrete stub columns. The beams may be 'slim floor' type sections which support the floors within their structural depth in order not to increase the overall building height.
For a 6 storey concrete building, the addition of one new habitable floor will add less than 10% to the loads on the existing building, taking account of the lightweight nature (< 1.5 kN/m^2 self weight) of the new structure.

The primary frame is manufactured from cold rolled, lightweight galvanised steel sections in the form of lipped and open channels. The cold rolled sections are dimensionally accurate, extremely robust, non-combustible and can be installed very quickly.

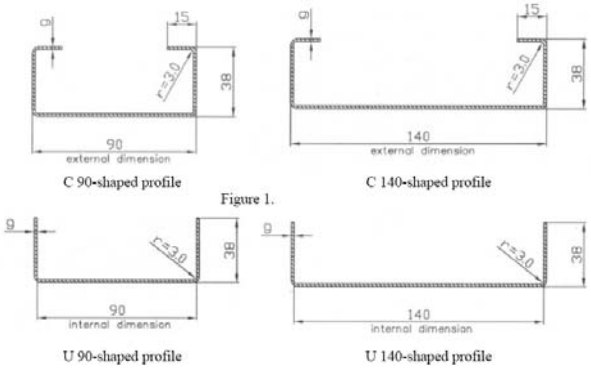


Figure 1.

Prefabricated building elements

Prefabricated elements for facades, roof and floor can all be supplied fully insulated, fitted with doors and windows according to the architect's specifications.
Advantages of using prefabrication can be resumed as follow:

- the time schedule and on-site span: quick assembly, reduce of water penetration in the building;
- the labour cost;
- reproducibility;
- quality performance

Building elements processed in dry and controlled condition will reduce the weather dependency and the overall quality.
Described as a modern method of construction, this involves the preassembly of almost all the components at the factory premises, transportation to site and then lifting into position with a high level of precision.

Facades made with steel frame or steel sheets.

It is possible to renew the existing facades or to upgrade the insulation of an existing building by removing or not a part of external skins. With glass, insulation products or even other materials, the steel products allow providing a solution which answers the thermal, acoustics and aesthetic constraints.

6 Refurbishment with steel: what are the advantages?

When the original building is in steel, it is not possible to rehabilitate it with a concrete solution. At the opposite when the existing building is made of concrete the choice of material exists: steel has already some advantages!

- *Architectural diversity and freedom of design:*
  The use of steel offers potential for adaptation and transformation, thanks to long spans, large and adaptable floors, internal and free volumes. These qualities also allow in the future answering the evolution of needs and uses.

- *Ease and speed of construction:*
  The two compelling arguments in favour of steel are ease and speed of construction. Made to the factory, the steel structure is easy to store in the site and very rapid to be assembled. Steel frames are also suited where access is difficult.
- *Lightness:*
  The lightweight technical solutions of steel enable the limitation of loads (on existing structure), the reduction of number and sections of columns, the impact on basement because any weight reduction is important.
- *Precision and reliability of steel products:*
  Usually manufactured on NC machines, steel frames are precise and, therefore, cause few complications on site. The ratio strength/size is excellent.
  Dimensional and mechanical characteristics of steel products are guaranteed and a wide range of forms and colours is proposed.
- *Thermal Comfort:*
  Steel refurbishment offers the possibility of adding thermal insulation externally and upgrading the performance in energy savings.
- *Compliance with Fire regulations:*
  Steel is non-flammable and does not contribute any additional fire load. Today, European legislation is more realistic and fire engineering raise the obstacles to the use of the steel.
- *Longevity of steel structures:*
  Easy to maintain, steel structures are undemanding in terms of maintenance. Protection of elements against corrosion (or fire) involved well-known and reliable methods. At last, steel is better able to withstand earthquakes.
- *Environmentally friendly:*
  On construction site, the disturbance to the neighborhood is reduced and time is short: less waste and less noise. Steel sections are also produced entirely from recycled materials. As steels are infinitely recyclable, buildings at the end-of-life can be easily and cleanly deconstructed or dismantled