DESIGN, BUILDING SOLUTIONS AND PERFORMANCES FOR STEEL FRAMED HOUSES

Teză destinată obţinerii
titlului ştiinţific de doctor
la
Universitatea "Politehnica" din Timişoara
în domeniul INGINERIE CIVILA
de către

arh. Mihai Muţiu

Conducător ştiinţific: Prof.Univ.Dr.Ing Dr. H.C. Dan Dubina
M.C. al Academiei Romane
Referenţi ştiinţifici: Prof.Univ.Dr. Ing. Raffaele Landolfo
Prof.Univ.dr.arh. Nicolae Lascu
Prof.Univ.Dr.Ing. Daniel Grecea

Ziua susţinerii tezei: 08 septembrie 2011

Seriile Teze de doctorat ale UPT sunt:

1. Automatică
2. Chimie
3. Energetică
4. Ingineria Chimică
5. Inginerie Civilă
6. Inginerie Electrică
7. Inginerie Electronică şi Telecomunicaţii
8. Inginerie Industrială
9. Inginerie Mecanică
10. Ştiinţa Calculatoarelor
11. Ştiinţa şi Ingineria Materialelor
12. Ingineria sistemelor
13. Inginerie energetică
14. Calculatoare şi tehnologia informaţiei

Universitatea „Politehnica" din Timişoara a iniţiat seriile de mai sus în scopul diseminării expertizei, cunoştinţelor şi rezultatelor cercetărilor întreprinse în cadrul şcolii doctorale a universităţii. Seriile conţin, potrivit H.B.Ex.S Nr. 14 / 14.07.2006, tezele de doctorat susţinute în universitate începând cu 1 octombrie 2006.

România, 300159 Timişoara, Bd. Republicii 9,
tel. 0256 403823, fax. 0256 403221
e-mail: editura@edipol.upt.ro

Acknowledgemets

To the memory of my parents

The thesis was developed during the period 2003-2011, and it is based on a number of low rise residential building projects, designed in cooperation with the Department of Steel Structures and Structural Mechanics, CMMC, from the " Politehnica" University Timisoara.

Firstly, I would like to express my gratitude to my advisor, Prof.Dr.Ing. Dr. H.C. Dan Dubina, MC Romanian Academy, for his encouragement, guidance and patience, throughout the research activity and in general , for his support in the making of this thesis.

It is important for me to stress out that the practical applications and case studies presented in this thesis are the result of team work.

Indeed, in the last twelve years, both the design work done with the structural engineering team lead by Prof. Dubina, as well as the scientific materials produced jointly , gave me the opportunity to work with almost all of Department's staff. I would like to take her the opportunity to thank them all for their cooperation , and more specially Prof.Dr.Ing. Daniel Grecea, Conf.Dr.Ing. Raul Zaharia, Conf. Dr.Ing. Viorel Ungureanu and Dr.Ing. Ladislau Fulop.

I would like as well to express my gratitude to Prof.Dr.Arh. Theodor Gheorghiu, for his continuous support and welcomed critical suggestions.

In the end, I would like to bring special thanks to my design team, arch. Oana Gherman , Ing. Ionut Sava, Ing. Ovidiu Ivascu si Stud.ing. Stefan Gorbe for their studio activity, which made possible the residential building projects presented here.

Last but not least I would like to express my whole gratitude to my wife, for her steadfast support and patience throughout this undertaking.

Muţiu, Mihai

Title of Thesis: **Design, Building Solutions and Performances for Steel Framed Houses**

Teze de doctorat ale UPT, Seria 5, Nr. 77, Editura Politehnica, 2011, 404 pagini, 333 figuri, 32 tabele.

ISSN: 1842-581X

ISBN: 978-606-554-329-4

Cuvinte cheie:
sustainable development, steel frame, low rise residential construction, integrated design, structural design, light gauge steel framing, hot-rolled profiles, thermal insulation, thermal bridge, layout, open plan, architectural design, case study

Rezumat,
The thesis investigates the use of steel framed structures for low rise residential buildings.
The main practical objective of the thesis is to analyze and validate the field results obtained by our design team during the last decade, and to demonstrate in the process the interest of implementing, on a larger scale, such construction methods on the Romanian residential market. The thesis is divided in 7 chapters and demonstrates the viability and efficiency of steel frame structures for low rise residential construction, by means of critical analysis and experimental investigation.

TABLE OF CONTENTS

6. Applications and Case Studies

List of Tables

Chapter 2

Chapter 5

Chapter 6

List of Figures

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 6

Rezumat

Prezenta teza studiaza problematica utilizarii structurilor metalice la proiectarea si executia locuintelor cu regim redus de inaltime. Scopul principal al acestei lucrari este acela de a analiza si de a valida rezultatele practice, obtinute de autor si echipa de proiectare din care face parte, in timpul ultimului deceniu si sa demonstreze avantajele implementarii pe o scara larga, a acestor sisteme constructive , in Romania.

Teza este impartita in 7 capitole, pe parcursul carora se incearca demonstrarea viabilitatii si a eficacitatii sistemelor structurale studiate, prin metoda analizei critice, a simularilor numerice si a incercarilor ecperimentale.

Capitolul 1. Introducere

Se prezinta subiectul tezei ,scopul si obiectivele, justificate in contextul actual impreuna cu parametrii si structura generala de cercetare de cercetare. Sunt prezentate pe scurt ideile principale si continutul fiecarui capitol.

Capitolul 2. Crestere economica si construire durabila

Construirea durabila are ca scop, integrarea obiectivelor de dezvoltare durabila in procesele tipice industriei constructiilor. Ea este asociata in general cu performantele ecologice ale produselor si ale materialelor.

Termenul de construire durabila se refera la crearea unui mediu *sanatos* folosind principii ecologice si eficiente din punct de vedere al resurselor. Termenul este in general folosit pentru a descrie un proces care incepe cu mult inaintea construirii efective(in stadiul planificarii si al proiectarii) si care continua dupa terminarea efectiva a constructiei. In timp ce normele de construire sunt determinate de consideratii economice pe termen scurt, construirea durabila este bazata pe cele mai bune practici care redau accesibilitatea pe termen lung, calitate si eficienta. La fiecare stadiu de viata al unei cladiri, creste confortul si calitatea vietii in defavoarea impactului negativ asupra mediului si in acelasi timp creste durabilitatea economica a proiectului. O cladire proiectata si construita intr-un mod durabil, minimalizeaza consumul de apa, materiale si energie de-a lungul intregului ciclu de viata al acesteia.

Construirea durabila, inseamna orase si cladiri care raspund nevoilor emotionale si psihologice ale oamenilor prin inlesnirea si stimularea protectiei mediului, prin constientizarea valorilor importante si insufletirea spiritului uman si prin apropierea societatilor, comunitatilor si a vecinatatilor.

Capitolul 3. Construirea durabila si sectorul rezidential

Pornind de la consideratii generale privitoare la specificului proiectarii locuintelor cu regim de inaltime redus si la conditionarea acestuia de cerintele pietii, analiza este mai apoi extinsa la provocarile si tendintele caracteristice arhitecturii rezidentiale de astazi.

O privire asupra evolutiei caselor rezidentiale, scoate in evidenta faptul ca tendinta generala de-a lungul anilor a fost aceea de crestere a suprafetelor locuite si continua preocupare de flexibilizare a planului.

A *construi verde* e modalitatea de a crea structuri si de a folosi procese care sunt responsabile ecologic si eficiente de-a lungul ciclului de viata al unei cladiri, de la amplasare la proiectare, construire, folosire, intretinere, renovare si demolare.Aceasta practica extinde si completeaza aspectele proiectarii clasice a cladirilor, care implica economia, utilitatea, durabilitatea si confortul.

In acest context, cladirile cu structura metalica reprezinta unul din raspunsurile pe care sectorul constructiilor l-a gasit pentru a raspunde provocarilor ridicate de dezvoltarea durabila.

Capitolul 4. Proiectarea de arhitectura si solutii constructive pentru casele cu structura metalica

Capitolul 4 analizeaza impactul pe care conceptul arhitectural il are in gasirea solutiilor constructive pentru casele cu structura metalica.

O scurta istorie a cladirilor rezidentiale cu structura metalica, arata ca introducerea si acceptarea treptata a acestui tip de constructie, au fost influentate de progresul tehnologic de evenimentele istorice si de economie.

Solutiile arhitecturale pentru cladiri cu structura metalica prezentate in continuare, sunt grupate in categorii impuse de elemente de proiectare ca de exemplu organizarea planimetrica, sistemul structural si tipul de anvelopa.

Versatilitatea sistemului constructiv cu structura metalica favorizeaza expresii arhitecturale variate. Casele cu structura metalica au potentialul de a ingloba atat proiecte inovative cat si capacitatea de a incorpora forme arhitecturale traditionale.

Capitolul 5. Proiectarea integrata si solutii pentru casele cu structura metalica

Proiectarea integrata se distinge de proiectarea conventionala prin efortul de a sintetiza inca de la inceput, in conceptul initial, toti parametrii relevanti ai proiectului. In acest fel se incearca contracararea efectelor proiectarii de tip secvential si in fapt, armonizarea solutiei, in functie de cerintele specifice ale fiecarei discipline angrenate in proiect.

Dimensiunile relativ reduse ale proiectelor rezidentiale (locuinte cu regim de inaltime redus),presupun echipe de proiectare mai restranse, ce favorizeaza astfel comunicarea interdisciplinara si aplicarea acestui concept.

Capitolul 6. Aplicatii si studii de caz

Acest capitol prezinta sapte exemple de tehnologii durabile, care folosesc otel sau combinatii de otel si lemn pentru realizarea structurii de rezistenta. Din cele sapte exemple prezentate, cinci sunt construite si locuite. Studiile de caz propriu-zise sunt in numar de trei dintre care doua sunt case unifamiliale iar unul, o vila urbana. Patru dintre exemple sunt studii de solutie.

Toate exemplele sunt situate in zone seismice cu risc seismic mediu si ridicat.

Capitolul 7. Concluzii

Capitolul final sintetizeaza toate concluziile partiale ale tezei si evidentiaza contributiile autorului referitoare la subiectul ales.

Summary

The thesis investigates the use of steel framed structures for low rise residential buildings.

The main practical objective of the thesis is to analyze and validate the field results obtained by our design team during the last decade, and to demonstrate in the process the interest of implementing, on a larger scale, such construction methods on the Romanian residential market. The thesis is divided in 7 chapters and demonstrates the viability and efficiency of steel frame structures for low rise residential construction, by means of critical analysis and experimental investigation.

Chapter 1. Introduction

It presents the thesis's subject (motivation), the goals and objectives, their justification in the present context, together with the research framework situated within national/international projects, in which the author and the design team of which he is part, were involved.

Chapter 2. Development and Sustainable Construction

The concept of sustainable construction aims at integrating the objectives of sustainable development into the construction activities. It is generally understood in relation with the environmental performance of products and assets (environmental sustainability).

The term sustainable construction refers to the creation of a healthy built environment using resource-efficient, ecologically-based principles. The term is generally used to describe a process which starts well before construction per se (in the planning and design stages) and continues after the construction team has left the site.

While standard building practices are guided by short term economic considerations, sustainable construction is based on best practices which emphasize long term affordability, quality and efficiency. At each stage of the life cycle of the building, it increases comfort and quality of life, while decreasing negative environmental impacts and increasing the economic sustainability of the project. A building designed and constructed in a sustainable way minimizes the use of water, raw materials, energy, land over the whole life cycle of the building.

Sustainable construction means cities and buildings that respond to the emotional and psychological needs of people by providing stimulating environments, raising awareness of important values, inspiring the human spirit, and bonding societies, communities, and neighbourhoods. [13]

Chapter 3. Sustainable Low Rise Residential Construction

Starting with general considerations on the specifics of low rise residential design and its interconnectivity to market constraints, the analysis is then extended to the challenges and trends characteristics of residential architecture today.

An overview of the evolution of residential layouts, points out to the fact that the general tendency over the years was the increase of house sizes and the search for plan flexibility.

Low energy building is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a

building's life-cycle from sitting to design, construction, operation, maintenance, renovation and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. Low energy building is also known as a sustainable or high performance building.

Within this context, steel framed buildings represent one of the answers the construction sector has found in order to meet the challenges raised by sustainable development.

Chapter 4. Architectural Design and Solutions for Steel Framed Houses

Chapter 4 analyses the bearing architectural design has on determining building solutions for steel framed houses.

A short history of steel framed residential construction, shows that the introduction and the gradual acceptance of this type of buildings, was influenced by technological progress, historical events and economics.

The architectural solutions for steel framed houses presented further, are grouped into categories, following design elements, such as layout, framing system, envelope and architectural style.

Buildings are judged more often than not by their architectural expression therefore the versatility of steel framed houses to accommodate various architectural styles constitutes a real advantage. Steel framed houses have the potential to support both innovative designs and the capability to incorporate traditional architectural form.

Chapter 5. Integrated Design and Building Solutions for Steel Framed Houses

Integrated design is distinguished from conventional design by its use of a highly collaborative, multidisciplinary project team. The team works as a collective to understand and develop all aspects of the design. The design can then emerge organically, with the full benefit of each expert's input—a structural engineer can contribute to the elegance and efficiency of the structure, a mechanical engineer can inform choices that enhance energy efficiency and comfort, a landscape architect and civil engineer can optimize the layout and orientation, an interior designer can improve the indoor spaces, a contractor can enhance the constructability of the resulting design, and a cost estimator can manage the budget.

Chapter 6. Applications and Case Studies

The chapter presents seven examples of sustainable technologies, which use steel or combine steel and timber for framing, with a choice of different materials for cladding, roofing and flooring, leading to high thermo-energetic performance. Of the four examples, all of them built in Romania and designed by the authors, three are single family houses and one a low rise apartment building. All the examples are located in medium and high risk seismic regions.

The driving design concept was to provide for flexible layouts, building upgrading, quality construction and high thermo-energetic performance, all to be achieved at a reasonable cost.

Chapter 7. Conclusions

The last chapter synthesizes all partial conclusions of the thesis and highlights the author's contribution regarding the chosen subject.

1. Introduction

1.1. Motivation

The thesis investigates design criteria, building solutions and economics of steel framed houses design and construction, viewed from both the architectural and engineering perspectives, all within the larger context of today's sustainable construction philosophy.

This double perspective is prompted by our belief that present and future development challenges will ultimately bring together even more, these two branches of the art of building.

In the same time, despite the fact that this construction method is widely used abroad, few applications are found in our country.

1.2. Objective and Goals

The main practical objective of the thesis is to analyze, validate and subsequently disseminate the practical results obtained by our design team during the last decade, and to demonstrate in the process the interest of implementing, on a larger scale, such construction methods on the Romanian residential market.

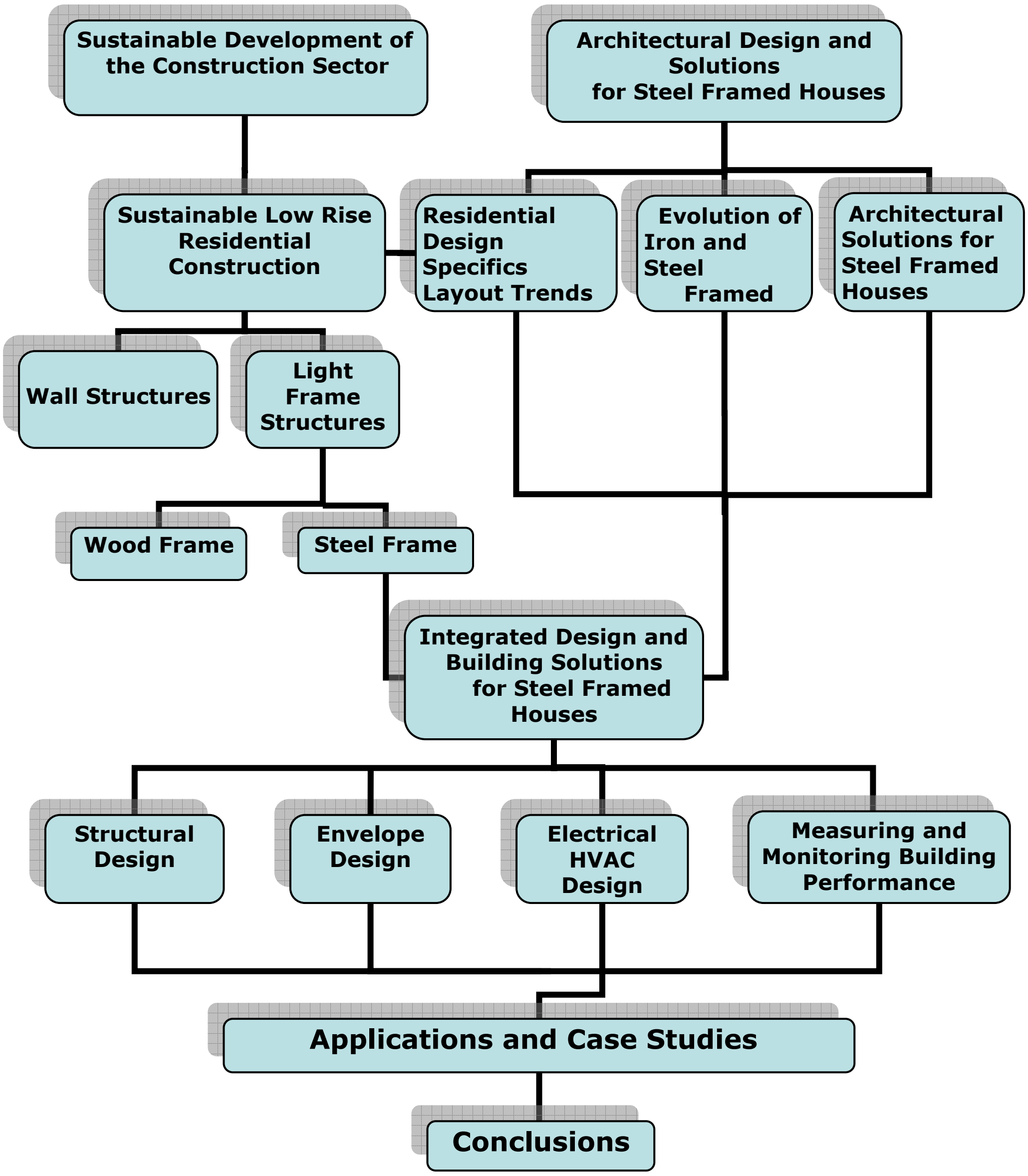
1.3 Research Framework

This thesis is based essentially on real construction projects and therefore the working hypothesis taken into consideration are definitely restricted by economic realities.

The results of the preliminary studies, the analyses and the experimental work were presented and disseminated at various scientific events organized by the CMMC department of the Civil engineering Faculty within Universitatea "Politehnica" Timisoara, such as :

The most important international project to date, in which the practical knowledge accumulated by the our design team, was put to work is the 'Arcelor-Mittal Affordable House ', jointly organized by Arcelor-Mittal Research Branch and the Universite de Liege. In this project the author and the structural engineering team lead by Prof.Dr.Ing. Dan Dubina M.C. Romanian Academy and Conf.Dr.Ing. Viorel Unguraenu , represented Romania, alongside Brazil, China, The Czech Republic, India, Sweden, Poland, and Portugal.

Design, Building Solutions and Performances for Steel Framed Houses



2. Development and Sustainable Construction

2.1. Introduction

Forty years ago, in 1971 Ian McHarg, delivered a speech at the North American Wildlife and Natural Resources Conference in Portland, Oregon, called "Man: Planetary Disease". In the speech he asserted that, due to the views of man and nature that have infiltrated all of western culture, we are not guaranteed survival.

Of man, McHarg said, "He treats the world as a storehouse existing for his delectation; he plunders, rapes, poisons, and kills this living system, the biosphere, in ignorance of its workings and its fundamental value."

About the same time, Konrad Lorenz, the Nobel prize winner for medicine (1973), also predicted the relationship between market economics and the threat of ecological catastrophe. In his 1973 book, *Civilized Man's Eight Deadly Sins*, Konrad Lorenz addresses the following paradox:

"All the advantages that man has gained from his ever-deepening understanding of the natural world that surrounds him, his technological, chemical and medical progress, all of which should seem to alleviate human suffering... tends instead to favor humanity's destruction.”

This is to say that today’s attitude towards the environment was pioneered some time ago, by far seeing individuals, who, through their teachings and overall activity, paved the way for a new approach which became the norm nowadays.

2.2. Environmental Impact of the Construction Industry

The construction industry imposes considerable loading on the environment and impacts severely on practically every environmental issue affecting sustainability, with buildings and building construction services accounting for around a half of total energy consumption in most developed countries.

Construction is one of the largest industries in both developing and developed countries in terms of investment, employment and contribution to GDP. Its impact on the environment is considerable particularly in areas of energy use, soil degradation, loss of agricultural land, forests and wildlands, air and water pollution, and depletion of non–renewable energy sources and minerals (Spence and Mulligan, 1995). The construction industry accounts directly and indirectly for nearly 40% of the material flow entering the world economy (Roodman and Lenssen, 1995) and in developing countries for around 50% of the total energy consumption (Levin, 1997; Bonini and Hanna, 1997; Vale et al, 1994). [1]

Buildings produce half of all greenhouse gases and account for one-sixth of the world's freshwater withdrawals, one-quarter of its wood harvest and two fifths of its material and energy flows. By several estimates, we will double the size of the built environment over the next twenty to forty years. For these reasons there is a critical and immediate need to shift thinking on how the built environment is designed. [2]

The impact on the environment results from pollutants, energy consumption, water consumption, land degradation/consumption, resource consumption, waste production and loss of biodiversity incurred throughout the life cycle of buildings, from raw material extraction, processing, construction, building operation and demolition.

According to Levin (1997) the contribution of buildings to the total environmental burden ranges between 12–42% for the eight major environmental stressor categories: use of raw materials (30%), energy (42%), water (25%) and land (12%), and pollution emission such as atmospheric emissions (40%), water effluents (20%), solid waste (25%) and other releases (13%). [1]

The construction industry has a significant impact on the environment across a broad spectrum of its activities loosely grouped into off–site, on–site and operational activities. Off–site activities include: mining and manufacturing of materials and components; transportation of materials and components; land acquisition; project definition and design. Their impact on the environment can be significant in the following areas:

· consumption of renewable and non–renewable resources such as minerals, water and timber for building materials and components. This may also lead to the loss of bio–diversity;

· pollution of air, water and land from manufacturing and transportation;

· committing land for a new facility may lead to deforestation, loss of agricultural
land, expansion of urban areas with associated transport and social problems, more demand for water, electricity and other services, and loss of bio–diversity;

· decisions about project goals influence design, construction and operation of the facility in areas of resource usage, quality of indoor environment, traffic issues, recycling, waste management, maintenance and life of the facility as well as social environment. [1]

Much of the waste and consumption occurs during the extraction and processing of the raw material. Mining requires water and energy, consumes land and produces significant quantities of acid and heavy metal contaminated gas, liquid and solid wastes. Timber requires significant tracts of land and amounts of fertilizer and harvesting and processing it requires energy. It is also often grown in plantations which replace old growth forest and significantly reduces biodiversity. Transportation of the material also requires energy and the fossil fuels used for transportation, extraction and harvesting produce greenhouse gases and a range of air pollutants. Processing of metals and minerals often results in major gas emissions; the concrete industry is a major producer of CO_2 while aluminum smelting produces perfluorocarbons, which are very powerful greenhouse gases. Hazardous wastes are often a byproduct, containing heavy metals and, from aluminum smelting, cyanide wastes. Processing of timber includes treatment against rot and pests and usually requires hazardous materials. [3]

On–site construction activities are related to construction of a physical facility, the impact of which may be found in the areas of: pollution of air, water and ground; consumption of resources in building the facility; traffic problems related to site activities; generation of construction waste; absence of recycling of construction materials and components; and loss of bio–diversity. [1]

Operational activities are those associated with operating the asset and include maintenance and future demolition/deconstruction of the asset. These activities may significantly impact on the environment in areas such as: energy and water consumption; pollution of air, water and ground; traffic problems caused by the physical presence of the facility and in– and out–flow of its occupants; generation of waste (sewerage, drainage and garbage); and indoor air quality. [1]

Each year, some three billion tonnes of raw materials – 40-50% of the total flow in the global economy – are used in the manufacturing of building products and components worldwide (Roodman and Lenssen 1995; Anink et al. 1996). Raw materials for the building sector are extracted, processed, transported, added in the construction phase and finally disposed. All these stages imply a number of environmental impacts. In particular, the building sector is a heavy consumer of materials with high embodied energy content, whose production usually depends on the use of fossil fuels, resulting in CO_2 emissions.[4]

Modern buildings consume energy in a number of ways. As analyzed by Jones (1998), energy consumption in buildings occurs in five phases. The first phase corresponds to the manufacturing of building materials and components, which is termed embodied energy. The second and third phases correspond to the energy used to transport materials from production plants to the building site and the energy used in the actual construction of the building, which are respectively referred to as grey energy and induced energy. Fourthly, energy is consumed at the operational phase (operation energy), which corresponds to the running of the building when it is occupied – usually estimated at 100 years, although this figure varies from country to country. Finally, energy is consumed in the demolition process of buildings as well as in the recycling of their parts, when this is promoted (demolition-recycling energy). [4]

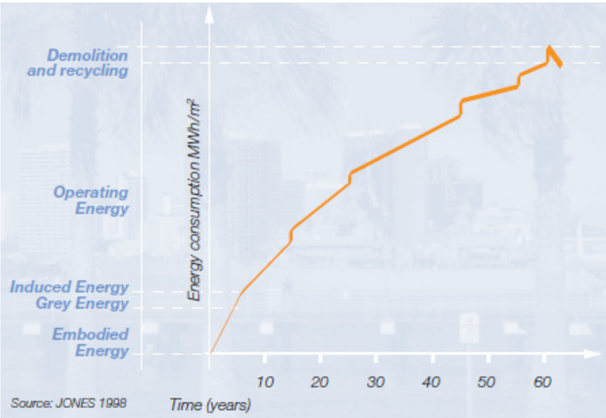


Fig. 2.1 *Energy consumed in the life of a building, estimated at 60 years.*

In most countries, residential buildings are responsible for a major part of the energy consumption of the building sector, even if the share of commercial buildings such as offices is also important. Studies indicate that, on average, buildings in Europe account for 36% of the energy use: the non-residential sector accounts for 8.7% and the residential sector for 27.5% of the total (Earth Trends 2005; ATLAS 2006). [4]

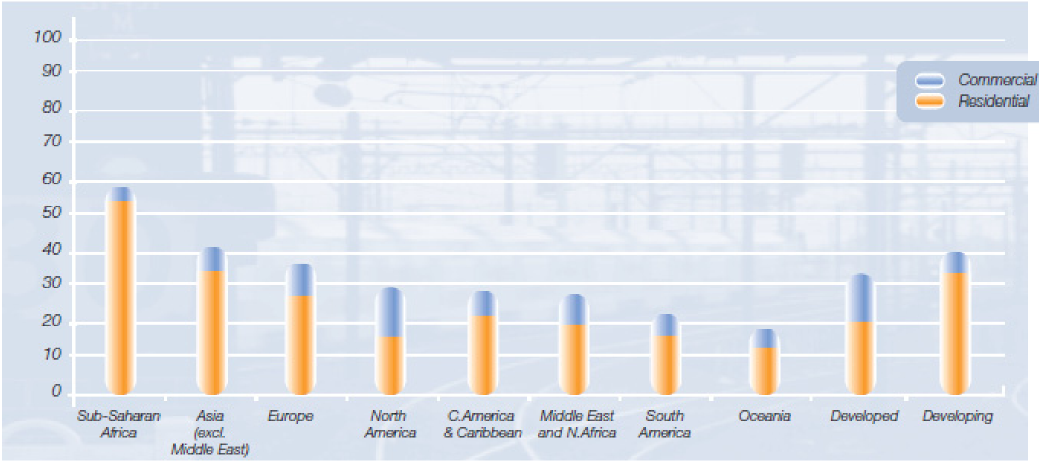


Fig. 2.2 Shares of energy use in different building sectors in the world, percentage of total energy use *Source : Earth Trends 2005 [4]*

Worldwide, 30-40% of all primary energy is used in buildings. While in high- and middle-income countries this is mostly achieved with fossil fuels, biomass is still the dominant energy source in low-income regions. In different ways, both patterns of energy consumption are environmentally intensive, contributing to global warming. Without proper policy interventions and technological improvements, these patterns are not expected to change in the near future. The pattern of energy use in buildings is strongly related to the building type and the climate zone where it is located. The level of development also has an effect. Today, most of the energy consumption occurs during the building's operational phase, for heating, cooling and lighting purposes, which urges building professionals to produce more energy-efficient buildings and renovate existing stocks according to modern sustainability criteria. [4]

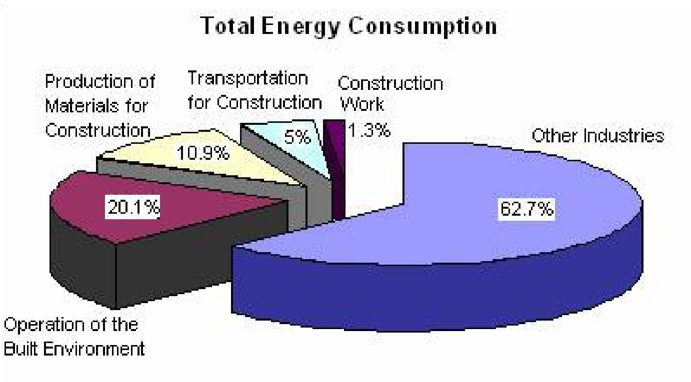


Fig. 2.3 Energy consumption by the construction industry

Vale et al (1994) measured the UK energy consumption related to buildings and building construction services to be up to 66% (inclusive of mining and manufacturing of building materials, transport, construction and operation) of the total energy consumption. Bonini and Hanna (1997) quoted a similar level of energy consumption (54%) in the USA construction industry. [1]

Energy consumption related to construction site activities is relatively low. In Australia, it is around 1% (Anon, 1996) of the national total and is only marginally higher in Denmark, where it was measured to be 3% (Olsen, 1998). On the other hand, transport of building goods by road consumes a significant amount of energy. In Denmark, the figure is around 45% of the national transport total (Olsen, 1998). When interpolated, this may represent around 10–15% of the total energy consumption (Edwards et al, 1996). Operation of buildings also consumes a significant amount of energy in maintaining a comfortable indoor environment and providing a range of services. According to Edwards et al (1996), this represents around 46% of the total energy consumption.[1]

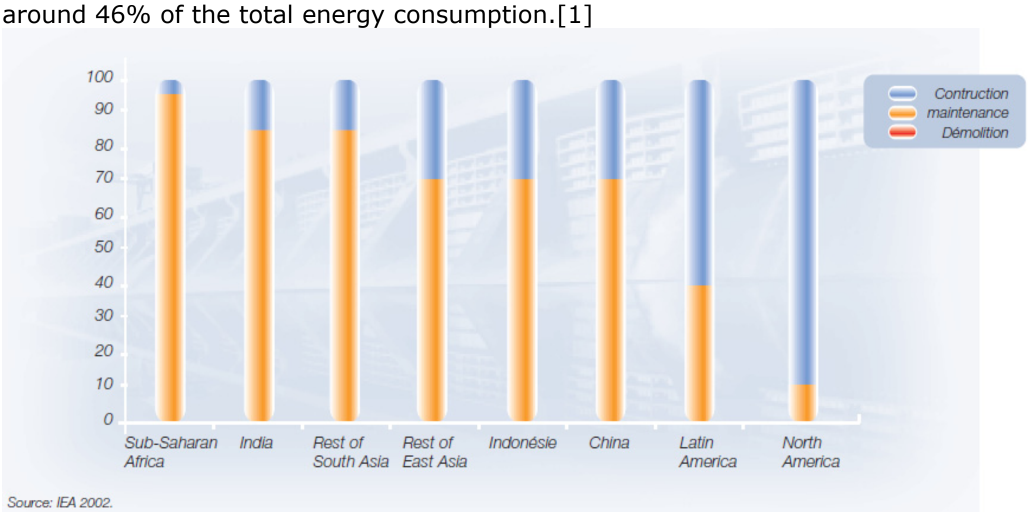


Fig. 2.4 Share of Traditional Biomass in Residential Energy Consumption, 2002

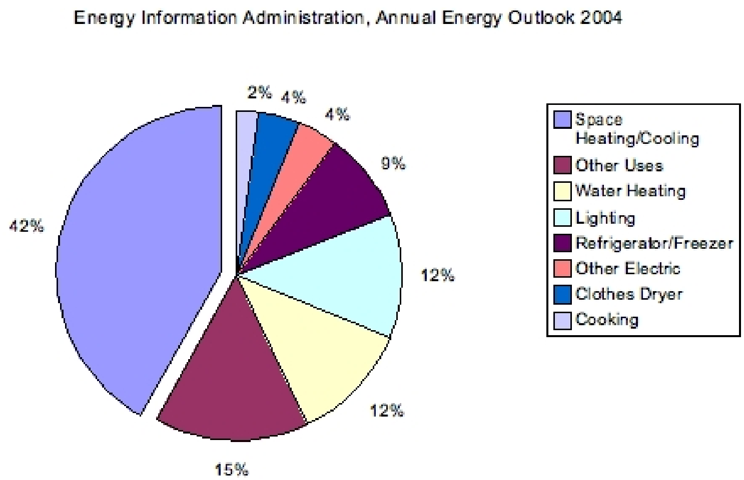


Fig. 2.5 Energy Consumption in a Typical House

BUPT

A by–product of energy consumption is emission of greenhouse gases, particularly CO2. It follows that the construction industry through a range of its activities rates as the most significant emitter of greenhouse gases. Edwards et al (1996) expressed the proportion of total CO2 emission arising from the operation of buildings in the UK to be at 48%. The total CO2 emission of the construction industry would be substantially higher if emissions caused by mining, manufacturing and transport of building materials as well as construction activities were included.[1]

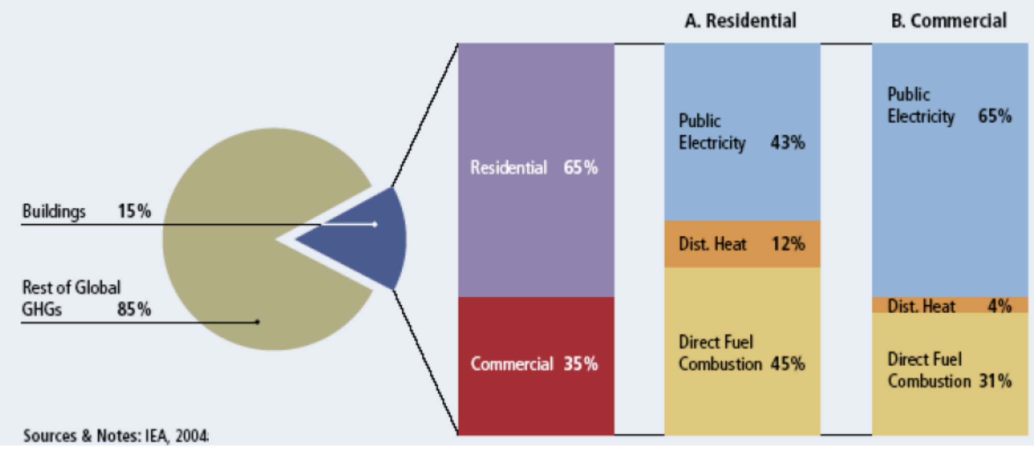


Fig. 2.6 Contribution of the built environment to the global GHG emissions

According to Roodman and Lenssen (1995), the construction industry utilises either directly or indirectly around 40% of the material flow entering the world economy. Cooper and Curwell (1997) estimated that the construction industry in the UK uses about 6 tonnes of building materials annually for every member of the population. [5]

While the construction industry is a significant consumer of energy and raw materials, it is also a significant consumer of other resources such as land and water. As the population continues to grow, the need to house people and industry, grow food, facilitate transport, build infrastructure facilities, and store drinking water will need to be satisfied. Existing urban areas will continue to expand as will rural settlements and recreational areas. The impact of new developments is two fold: it causes land degradation and erosion, surface and ground water pollution, and it contributes to land clearing required for new developments and the acquisition of more agricultural and grazing land.

Waste is generated throughout the life of a building and transported to landfills during building demolition, renovation, and construction. According to the U. S. Environmental Protection Agency, construction and demolition waste represents a quarter to a third of all waste landfilled in the United States.

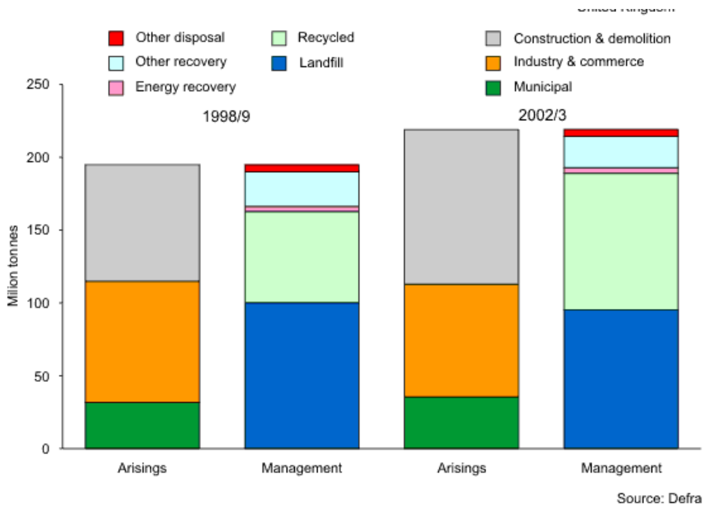


Fig. 2.7 Comparison between waste arising and waste management in the interval period 1989 -2003

The diversity of buildings, their distinct uses and extended life cycle pose a challenge for the prescription of energy conservation measures. Specific solutions are needed for each situation, such as for the construction of new buildings, for the renovation of existing ones, for small family houses and for large commercial complexes. Energy consumption can be reduced with thermal insulation, high performance windows and solar shading, airtight structural details, ventilation and heat/cold recovery systems, supported with the integration of renewable energy production in the building. These strategies apply to buildings in both warm and cold climates. Site and energy chain planning also influence the energy efficiency of the individual building. However, technological solutions will only be helpful when building occupants are committed to using energy-efficient systems in an appropriate way. [4]

2.3 Principles of Sustainable Development
Measuring and Monitoring Sustainable Development

The principles of sustainable development applied to construction today are not entirely new; in fact they are very similar to the unwritten rules that human kind used to observe since the beginning of time to roughly, the 1800, or the advent of industrial revolution.

In other words it is, in many ways, a coming back to the good old common sense.

According to the World Wildlife Fund (WWF), the ecological footprint (a hypothetical figure that expresses the pressure on our biosphere caused by our consumption in global hectares) has exceeded the world’s capacity already. This situation has disastrous consequences and is causing an irreversible decrease in biocapacity and an accumulation of waste. This is a trend that will continue into the next decades, especially because of increasing populations as well as expected increasing prosperity in the developing economies of Asia and South-America.[6]

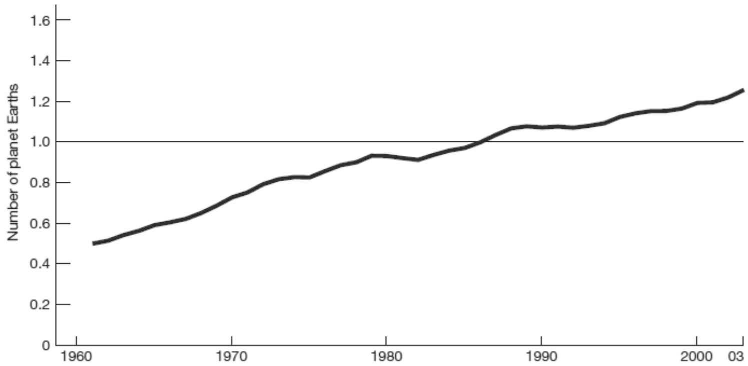


Fig. 2.8 Humanity's ecological Footprint 1961- 2003. WWF living planet report 2006

To put sustainability in context, the world's population has doubled over the past 40 years and industrial activity has increased sevenfold in that same period. The impacts of population growth and related industrial activity are being experienced at global, national, provincial and local levels. There are diverse opinions about the state of our environment and our ability to sustain current growth. There is, however, increasing agreement that current practices have resulted in significant problems today and will continue to do so unless answers to these problems are found very soon. [7]

Sustainable development has several definitions, such as:

- *"development that meets the needs of the present without compromising that ability of future generations to meet their own needs"* (the BRUNDTLAND Report WCED, 1987);
- *"improving the quality of human life while living within the carrying capacity of supporting ecosystems"* (Caring for the Earth, IUCN/UNEP 1991);
- *"development that delivers basic environmental, social and economic services to all residences of a community without threatening the viability of natural, built and social systems upon which the delivery of those systems depends"* (International Council for Local Environmental Initiatives, ICLEI 1996);
- *"determined to promote economic and social progress for their peoples, taking into account the principle of sustainable development and within the context of the accomplishment of the internal market and of reinforced cohesion and environmental protection, and to implement policies ensuring that advances in economic integration are accompanied by parallel progress in other fields"* (Amsterdam Treaty, 1997).

The triple bottom-line, often also referred to as People, Planet and Prosperity (formerly Profit) (Elkington, 1998) is the basic framework in which the main goals of sustainability are defined. Each of these three pillars, referring to sociological, ecological and economical aspects of our sustainability problems, can be looked at in more detail.

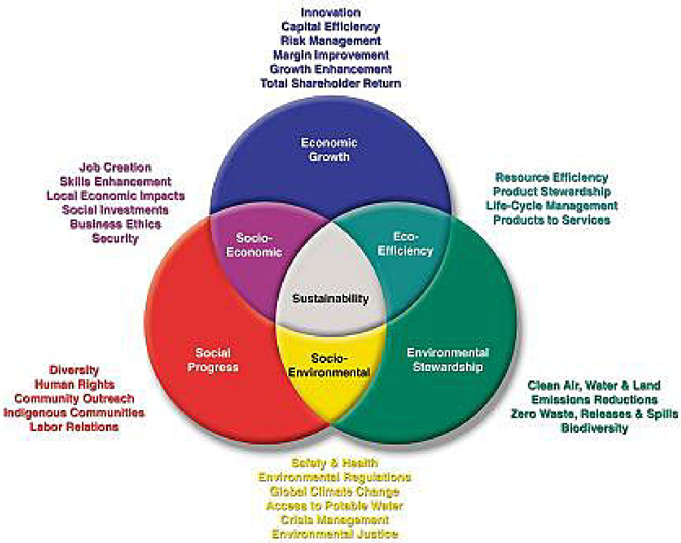


Fig. 2.9 Three main overlapping fields defining sustainable development

Each of these three pillars, referring to sociological, ecological and economical aspects of our sustainability problems, can be looked at in more detail:

Economic: An economically sustainable system must be able to produce goods and services on a continuing basis, to maintain manageable levels of government and external debt, and to avoid extreme sectoral imbalances which damage agricultural or industrial production.

Environmental: An environmentally sustainable system must maintain a stable resource base, avoiding over-exploitation of renewable resource systems or environmental sink functions, and depleting non-renewable resources only to the extent that investment is made in adequate substitutes. This includes maintenance of biodiversity, atmospheric stability, and other ecosystem functions not ordinarily classed as economic resources.

Social: A socially sustainable system must achieve distributional equity, adequate provision of social services including health and education, gender equity, and political accountability and participation.[8]

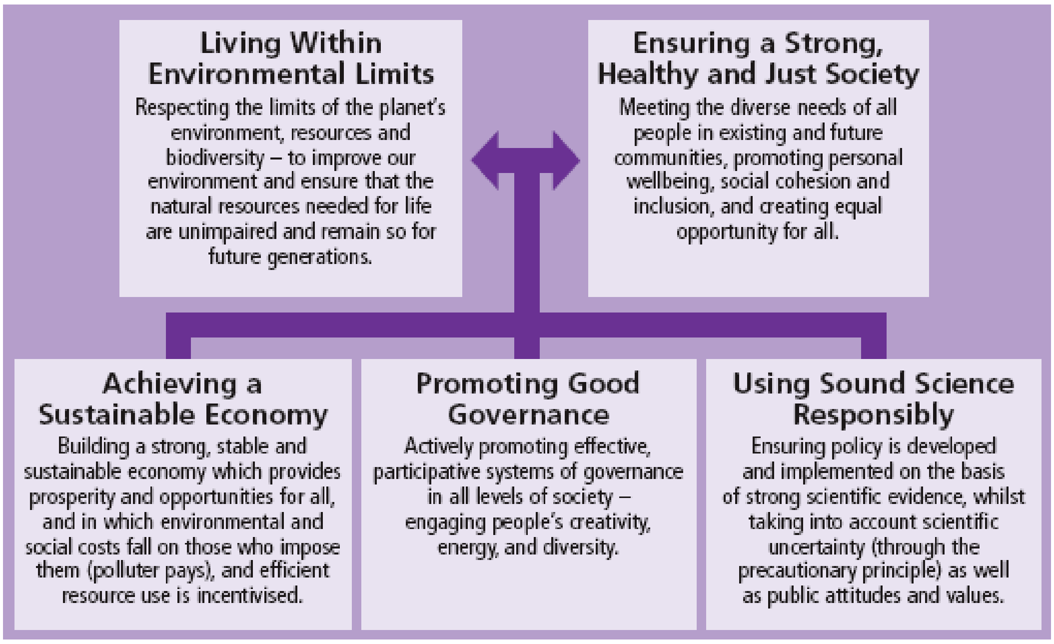


Fig. 2.10 The principles of sustainable development

The principles of sustainable construction emanate then from those of sustainable development with more focus on the specific impacts of the construction industry on the three elements of the triple bottom line. Many sets of principles have been defined by organisations and government bodies:

- Reduce resource consumption;
- Reuse resuouces
- Use recyclable resources
- Protect nature
- Eliminate toxics
- Apply life cycle costing

CIB 1994

- Reducing energy consumption, being more energy efficient, and using renewbale energy
- Choosing, using, re-using and recycling materials
- Producing less waste and recycling more
- Producing less toxicity, water, noise and spatial pollution

CIOB 2004

- Reduce energy consumption and associated emissions of carbon dioxide
- Minimise the use of resources
- Reduce the release of pollutants
- Maximise the use of sustainably sourced and recycled materials
- Promote sustainable transport choices

NAO 2007

Hill and Bowen (1997) present four pillars of *sustainable construction* (namely social, economic, biophysical and technical), each with a set of principles for sustainable construction. Each of these four pillars (and their related principles) are over-arched by a set of process-orientated principles, including:

- the undertaking of assessments prior to the commencement of proposed activities assists in the integration of information relating to social, economic, biophysical and technical aspects of the decision making process;
- the timely involvement of key stakeholders in the decision making process (WCED, 1987);
- the promotion of interdisciplinary and multi-stakeholder relations (between the public and private sectors, contractors, consultants, nongovernmental) should take place in a participatory, interactive and consensual manner;
- the recognition of the complexity of the sustainability concept in order to make sure that alternative courses of action are compared. This is so that the project objectives and the stakeholders are satisfied with the final action implemented;
- the use of a life cycle framework recognises the need to consider all the principles of sustainable construction at each stage of a project's development (i.e. from the planning to the decommissioning of projects);
- the use of a system's approach acknowledges the interconnections between the economics and environment. A system's approach is also referred to as an integrated (design) process;
- that care should be taken when faced with uncertainty;
- compliance with relevant legislation and regulations;
- the establishment of a voluntary commitment to continual improvement of (sustainable) performance;
- the management of activities through the setting of targets, monitoring, evaluation, feedback and self-regulation of progress. This iterative process can be used to improve implementation in order to support a continuous learning process;
- the identification of synergies between the environment and development.[9]

Sustainable Development Indicators [10]

Measuring and monitoring environmental conditions has been a major concern of Governments and international organizations during the 1990's. Some of the main international initiatives have included the activities of UNSTAT/UNEP, including the State of the World Environment and Environmental Data Report series (1994), the development of an Earthwatch database and the beginnings of the development of a series of environmental indicators. Other bodies such as OECD and WHO have been involved in the development of a conceptual framework.

Growing realization of the failings of the conventional GNP and income as the primary indicators of economic progress has led to the development of alternative yardsticks. Two interesting efforts are the Human Development Index (HDI) devised by the United Nations Development Programme and the Index of Sustainable Economic Welfare (ISEW). A third indicator, per capita grain consumption, is a useful measure of changes in well-being in low-income countries, where the data needed to calculate the more sophisticated indices are typically not available on an annual basis.

The Human Development Index, measured on a scale of 0 to 1, is an aggregate of three indicators: longevity, knowledge, and the command over resources needed for a decent life. For longevity, the UN team uses life expectancy at birth. For knowledge, they use adult literacy and mean years of schooling. And for the command over resources, they use gross domestic product (GDP) per person after adjusting it for purchasing power. Because these indicators are national averages, they do not deal directly with inequalities in wealth distribution, but by including longevity and literacy they do reflect indirectly the distribution of resources.

While the HDI represents a distinct improvement over income figures as a measure of human well-being, it so far says nothing about environmental degradation. As a result, the HDI can rise through gains in literacy, life expectancy, or purchasing power that are financed by the depletion of natural resources, setting the stage for a longer term deterioration in living conditions.

The Daly-Cobb Index of Sustainable Economic Welfare, on the other hand, is a more comprehensive indicator of well-being, taking into account not only average consumption but also distribution and environmental degradation. After adjusting the consumption component of the index for distributional inequality, the authors factor in several environmental measures, such as depletion of non-renewable resources, loss of farmland from soil erosion and urbanisation, loss of wetlands, and the cost of air and water pollution.

Chapter 40 of Agenda 21 calls for the development of indicators for sustainable development. In particular, it requests countries at the national level, and international governmental and non-governmental organizations at the international level to develop the concept of indicators of sustainable development in order to identify such indicators.

An increasing number of organizations has responded to the challenge of Agenda 21 to develop indicators for sustainable development in the short-term. Some of this work is being undertaken around specific issues, such as health and the environment, or human settlements; others are attempting to define a full set of indicators.

Sustainable development indicator classifications

Name	Description	Examples
Whole-society indicators: sustainability of a particular geographic region or political unit		
Global	Overall assessment of the current state of the world, mapped to *Agenda 21*	UN CSD, PAGE, Millennium Assessment, Ecological Footprint,
Regional/local	Response to Local *Agenda 21*: assessment of factors determined to be important for the local population	Pastille, Sustainable Seattle, Santa Monica, NRTEE
Organisation-based indicators: sustainability of the operations of an organisation		
Industry/NGOs	Indicators of how an organisation is performing in terms of a set of indicators for sustainable development	Global Reporting Initiative
Investor-based indicators: correlation of corporate sustainability with financial performance		
Project risk assessment	Principles, processes and indicators for assessing project risk	The Equator Principles
Financial performance	Any published index that tracks the financial performance of companies that have committed to sustainability principles	Dow Jones Sustainability Index FTSE4Good, Innovest, EcoValue21
"Green" funds	Funds holding investments in companies which they believe will have better than market returns owing to commitment to sustainability	Domini Social Equity Fund, Triodos Bank, SAM
Project-based indicators: assessment of a project's contribution to sustainability		
Project screening	Indicators for screening projects as to their likelihood of achieving sustainability outcomes	World Bank, The Equator Principles
Project performance	Contribution a project makes towards sustainable development Includes efforts made in the construction phase	SPeAR, CRISP, BEQUEST, LEED, CH2M HILL's 4-step screening

Tab. 2.1 Sustainable development indicator classifications

Economic indicators have been used for many years at national, regional and international levels. Social indicators have also been developed over the past years and are widely used all over the world. It is feasible to select among the economic and social indicators those which capture the specific issues most relevant to sustainable development. Institutional indicators related to Agenda 21 are largely undeveloped and are at this stage limited to so-called yes/no indicators. Environmental indicators have been developed more recently. For some of the environmental aspects, data will not be easily available. Recent initiatives include the environment statistics program of the United Nations Statistical Commission, environmental indicators being developed by UNEP, the UN system-wide *Earthwatch*, the OECD, various relevant international legal instruments, and so forth.

A core set of indicators is proposed for monitoring progress at a national level towards sustainable development through the implementation of Agenda 21. It is fully recognized that there is need for flexibility as the conditions, activities and priorities for sustainable development differ from country to country. At same time, the need for international comparability calls for the development of standardized concepts, definitions and classifications of indicators.

Eurostat has developed a set of Sustainable Development Indicators (SDIs), along with the help of a group of national experts known as the Task Force on Sustainable Development Indicators. A first set of indicators was adopted by the Commission in 2005 (CEC 2005b) and then updated in 2007.

On the construction and real estate sector, the sustainability indicators demonstrate the influences of the whole sector as well as those of planning, design, construction and use of a building. They may be used in evaluation of a building, enterprise, sector or even a simple construction product, expressed by the aid of parameters. The methods and tools to use indicators as a basis for decision-making in design, product development and construction processes are under development. Indicators are also an essential part of life-cycle analysis (LCA) methods whose implementation in the design and construction processes proceeds promisingly.

Housing Indicators:
Affordable and Adequate Housing

Access to Affordable Housing
Indicator HA1: Mortgage affordability
Defined as proportion of households who are eligible for and can afford the maximum loan on a median priced formal sector house.

Indicator HA2: Excessive housing expenditure
Defined as proportion of households in the bottom 40% of incomes who are spending more than 30% of their incomes on housing.

Indicator HA3: Economic share of housing
Defined as the proportion of national or city product due to rent or imputed rent of dwellings.

Indicator HA4: Transaction costs
Defined as proportion of the value of a median-priced formal sector house which must be spent to both buy and sell the house.

Indicator HA5: House price appreciation
Defined as the average annual real percentage of change of house prices over a five year period.

Adequate Housing for All
Indicator HA6: Overcrowding

Defined as the percentage of households who are in housing deemed to have too few bedrooms for a family of that type.

Indicator HA7: Households per dwelling

Defined as the ratio between the total number of households and the total number of occupied dwelling units of all types in the urban area.

Indicator HA8: Inadequate housing

Defined as the proportion of dwellings that are deemed to be inadequate or in need of major repairs.

Indicator HA9: Indoor plumbing

Defined as the percentage of dwelling units which contain a complete unshared bathroom within the unit.

Indicator HA10: Squatter housing

Defined as the percentage of the total housing stock in the urban area which is currently occupying land illegally.

Indicator HA11: Homelessness

Defined as the number of people per thousand of the urban area population who sleep outside dwelling units (eg on streets, in parks, railroad stations and under bridges) or in temporary shelter in charitable institutions.

Indicator HA12: Owner occupancy (by sex)

Defined as the percentage of households which own the dwelling units which they occupy for (a) all households, (b) female headed households.

Indicator HA13: Vacant dwellings

Defined as the percentage of the total number of completed dwelling units which are presently unoccupied.

RURAL HOUSING

Indicator HA14: Rural water/electricity connection

Defined as the percentage of rural dwelling units with a water or electricity connection in the plot they occupy.

Indicator HA15: Permanent rural housing

Defined as the percentage of rural dwelling units which are likely to last twenty years or more given normal maintenance and repair, taking into account locational and environmental hazards (eg floods, typhoons, mudslides, earthquakes).

Indicator HA16: Rural home ownership

Defined as the percentage of rural residents who own their dwellings.

Indicator HA17: Rural house price to income

Defined as the ratio of the median free-market price of a rural dwelling unit and the median annual rural household income.

Housing Provision

Land

Indicator HA18: Land availability

Defined as the number of serviced blocks currently available divided by the present construction rate in dwellings per month (annual average).

Indicator HA19: Planning permission multiplier

Defined as the ratio between the median land price of an unserviced plot on the urban fringe given planning permission for residential development, and the median price of a nearby plot in rural/agricultural use without such permission.

Indicator HA20: Formal land transaction

Defined as the percentage of the metropolitan area covered by a land registration system which allows for buying, selling, long-term leasing, or mortgaging urban land.

Indicator HA21: Development time

Defined as the median length in months to get approvals, permits, and titles for a new medium-sized (50-200 unit) residential subdivision in an area at the urban fringe where residential development is permitted.

Indicator HA22: Cost recovery

Defined as the percentage of total infrastructure costs recovered from new developments during the year.

Indicator HA23: Minimum lot size

Defined as the minimum lot size for a single family housing unit in a new 50-200 unit residential subdivision.

Indicator HA24: Land development controls

Defined as a composite of questions on land use and building code regulations.

Finance

Indicator HA25: Credit to value ratio

Defined as the ratio of new mortgage loans for housing last year to total investment in housing (in both the formal and informal sectors) last year.

Indicator HA26: Housing loans

Defined as the proportion of dwellings that have housing loans from the formal financial sector.

Indicator HA27: Mortgage-to-prime difference

Defined as the average difference in percentage points between interest rates on mortgages in both commercial and government financial institutions and the prime interest rate in the commercial banking system.

Indicator HA28: Mortgage-to-deposit difference

Defined as the average difference in percentage points between interest rates on mortgages in both commercial and government financial institutions and the interest rate on one-year deposits in the commercial banking system.

Indicator HA29: Arrears rate

Defined as the percentage of mortgage loans which are three or more months in arrears in both commercial and government financial institutions.

Indicator HA30: Mortgage loans for women

Defined as the percentage of mortgage loans granted to women to all mortgage loans made last year.

Construction

Indicator HA31: Construction cost

Defined as the present replacement cost (labour, materials, on-site infrastructure, management and contractor profits) per square meter of a median priced dwelling unit.

Indicator HA32: Construction time

Defined as the average time, in months, required to construct a median housing unit.

Indicator HA33: On-site productivity

Defined as the man-hours per square metre on a typical median-priced dwelling in the formal construction sector.

Indicator HA34: Industry concentration

Defined as the percentage of new formal-sector housing units placed on the market by the five largest developers (either private or public) last year.

Indicator HA35: Employment

Defined as the percentage of all employment that is engaged in the construction of residential dwelling units.

Indicator HA36: Wage labour

Defined as proportion of on-site building employees who are employed as wage labour.

Taxes and Subsidies

Indicator HA37: Effective taxation rate by tenure

Defined as the net annual housing-related taxation per dwelling paid by households to governments, in US dollars, for (a) owner occupied housing, (b) private rental housing, (c) public housing.

Indicator HA38: Nett housing outlays by government

Defined as the total expenditure by all levels of government on housing in the current year, net of all housing related receipts from the public, taken as a percentage of total government expenditure.

Indicator HA39: Property tax rate

Defined as the percentage of the market value of the median-priced dwelling unit which is collected as annual property tax.

PUBLIC HOUSING

Indicator HA40: Public housing stock

Defined as the percentage of the total number of dwelling units in the urban area that is owned, managed and controlled by the public sector.

Indicator HA41: Privatised public stock

Defined as the percentage of the total number of dwelling units previously constructed or managed by the public sector hat have been privatised.

Indicator HA42: Public housing production

Defined as the total production of public housing units as a fraction of all formal housing units produced during the year.

Indicator HA43: Social rent to income

Defined as the ratio of the median annual rent of a public housing dwelling unit and the median household income of renters of public housing.

Indicator HA44: Waiting time

Defined as the average time on waiting lists before allocation of public housing units.

Indicator HA45: Operating subsidies

Defined as the ratio of rent payments to operations costs for public housing.

Indicator HA46: Administrative costs

Defined as the administrative cost of operating public housing taken as a fraction of the estimated market rental value of the dwellings.

Indicator HA47: Tenant management

Defined as proportion of social housing stock managed by tenants, completely, partly or jointly.

Life cycle analysis

Most research work in the field of sustainable construction addresses the issue of improving environmental performance of building materials, components and even entire buildings. Improvements are beginning to materialise as evident from environmental life cycle assessments of physical facilities. These in fact represent improvements in environmental performance per unit of production.

Considerable work has gone into developing systems for measuring the environmental performance of buildings and physical facilities over their life cycle. Among the best known systems are BREEAM (UK), BRE Office Tool Kit (UK), Home Energy Rating (UK), BREDEM (UK), Waster/Environmental Data Sheet (Europe), European Eco–labelling (Europe), SIB (Switzerland), BauBioDataBank (Germany), Ecocerto (Italy), EcoLab (Netherlands), BIES Index (Australia), Athena (Canada), BEPAC (Canada), LEED (US). Although largely different from each other and designed around different indicators, these systems nevertheless have a positive impact on reducing environmental stress in the short–term. However, future work will need to be directed at developing a universal life cycle assessment system based on internationally agreed absolute indicators of environmental performance.[1]

Impacts of planning and design decisions at various phases of the project life-cycle on sustainable development

Project life-cycle phase				
Development	Planning, siting, design	Construction	Operation	Deconstruction, disposal
Decision				
Location Function Partnerships Financing Cost	Recycled materials use Openness of design Natural lighting use Access to transport	Recycling Disposition of construction waste	Energy efficiency Indoor air quality Materials use	Building reuse Ability to recycle building materials
Impact				
Access Quality User-occupant efficiency User-occupant comfort Community contribution	Materials intensity Energy efficiency User-occupant efficiency User-occupant comfort	Recycled materials use Construction environmental footprint	Occupant efficiency Occupant productivity	Resale value Redevelopment potential

Tab. 2.2 - Impacts of planning and design at various phases of the project life-cycle

Life cycle assessment methods employ a set of indicators of environmental performance against which the likely performance of the facility is assessed. However, there seems to be a lack of uniformity in the use of indicators in different life cycle assessment methods. In fact, there is no international agreement on what these indicators should be. Moreover, there is no agreement on what should be their values. In most cases, performance indicators are selected on the basis of some important local environmental issues that need to be addressed and their values set at a level that will achieve some marginal improvement in performance.

The capability of different solutions to fulfill the performance criteria can be studied with verification methods. They may be product information data from other industries and product manufacturers; or they may be simulation and visualization programs which handle large input data and use theoretically sound formulae. The level of consideration may also vary (building, system, single product). Verification methods of human and societal aspects are more value-bound, subjective and relative but some design guidelines can be found e.g. for accessibility.

The definition phase of a construction project is crucial for the realization of the sustainability goals because it includes the budget frame for construction, targets for operation costs (especially energy consumption) and quality specifications for example for the indoor climate and accessibility. The assessment of the ecological footprints of a building should be made using reliable and well-known methods, e.g. Life-Cycle-Analysis.

An assessment of environmental impacts of a process or a product is an analysis that is made by identification of what has been taken from the environment and what has been brought back, by recognition of the potential harms due to these actions and by rating the significance of the impacts. Consequently, the methods are developed to cope with the whole life-cycle of an object under review.

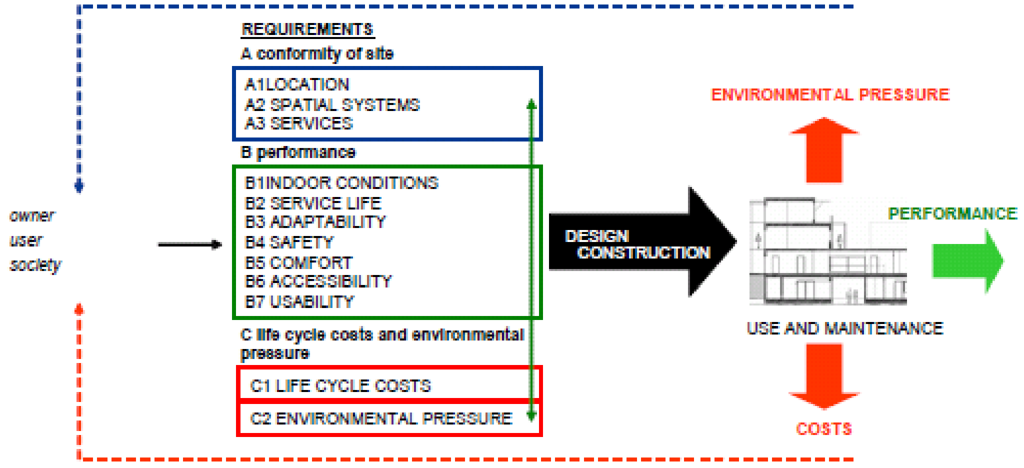


Fig. 2.11 Generic model of a building's performance analysis [11]

The Life-Cycle-Analysis (LCA) is internationally recognized as a usable approach to evaluate the environmental impacts of products or processes. The method has been under development and in use since the early 1960s, but it was only in the mid-to late 90s' that the protocol was standardized by the International Organization for Standardization (ISO14040-42). It is now being extended to construction.

The complete cycle of sustainable construction activities comprise the ways in which built structures and facilities are procured and erected, used and operated, maintained and repaired, modernized and rehabilitated, and finally dismantled and demolished or reused and recycled. [11]

Assessment of environmental impacts over the lifetime of built facilities as well as estimates of life cycle costs (LCC) should be made available to the clients before a construction project begins. Clients, architects and consulting engineers will be more and more asked to take into account environmental aspects in their designs, especially LCA and LCC considerations. The different methods should be integrated with other tools such as quantity surveying or energy simulation.[11]

Adoption of LCA in the construction sector is a cumbersome work as the buildings and works incorporates hundreds and thousands of individual products and in a construction project there are tens of companies involved. Further, the expected life time of a building is exceptionally long, tens or hundreds of years. The LCA fits best to the level of single product or material, and different approaches and tools to consider an entire building are under development. The feedback from real construction projects should be analyzed rationally and systematically in order to strengthen the evolution to generic transparent methods.[11]

In principle, the LCA can be used to identify stages that have greatest environmental impacts in the life cycle of a product and to compare several products having similar technical properties. For this purpose, there ought to be a common understanding on the performance objectives and relevant criteria of a building. This kind of general view can also be utilized in order to widen the scope of the environmental LCA to other sustainability aspects. The evolution can be regarded as an alternative or as a complement to the performance analysis presented previously.[11]

The functional performance aspects are in general not included methodologies and tools of environmental evaluation. As an unintentional consequence, it is common to regard sustainability only as "friendliness to the environment". Moreover, most of the assessment programs are not design-orientated, despite claims to the contrary. They are constructed to give endorsement to a completed design rather than to assist the designer during the design process. While "environmental assessment" of new and renovated buildings is potentially one of the biggest future uses of computer simulation, the conceptual work on appropriate methodologies is still in its infancy (Soebarto and Williamson 2001).[11]

Impact category	Current consequences
Global warming*	Low
Acidification*	High
Eutrofphication*	Medium
Fossil fuel depletion	Medium
Indoor air quality	Medium
Habitat alteration	Low
Water intake	Medium
Air pollutants	High
Smog	High
Ecological toxicity	Medium - Low
Ozone depletion*	Low
Human health	Medium - Low

Tab. 2.3 Weight of environmental impacts according to EPA's list.

The analysis and comparison of the functionality of construction solutions has to be carried out at the level of each element (interior walls, exterior walls, floor, roof, etc.), therefore each one of them presents distinct requirements.

The first step for the evaluation is to define functional parameters, e.g. thermal insulation, airborne and impact sound insulation, flexibility of natural illumination, structural stability, air permeability, etc. [11]

Economic and social indicators are often combined in sustainability evaluation. This tells on the one hand about their interrelation and, on the other hand, about the difficulties to find agreement. For example, the following social indicators are proposed: accessibility, security, sense of well-being, distance to school, movability and access to green areas, social services, health and comfort, cultural heritage. [11]

The construction solutions are very distinct at the level of the durability. It is essential to use the same study period for each alternative, whose LCCs are to be compared according to the stakeholder perspective. For example, a homeowner would select a study period based on the length of time he or she expects to live in the house, whereas a long-term owner/occupant of an office building might select a study period based on the life of the building. [11]

Once the list of indicators and their parameters is being set up, each parameter has to be quantified. The quantification is necessary in order to compare solutions, aggregate indicators and precisely assess the solution. Method of quantification should have been anticipated and different methods can be used: results from previous studies (databases), simulation tools, expert's opinion and data base processing (Cherqui, Wurtz and Allard 2004).

Measuring the economic performance of a building is more straightforward than measuring, for instance, the environmental performance. Standardized methodologies and quantitative published data are readily available.

The aggregation of the different parameters shall be developed after the quantification of each one. The aggregation is normally established giving an equal importance to all the indicators. The choice may be not the most correct one once the indicators are not expressed in the same order of magnitude and/or in the same unit. For example, the contribution of a material for the greenhouse effect is presented in the amount of carbon dioxide emitted, the acidification in equivalent of hydrogen ions, the electro fission in nitrogen equivalent, etc. On the other hand, the way that each parameter influences the sustainability is neither consensual nor unalterable along the time.[11]

Life-cycle cost analysis (LCCA) is a method for assessing the total cost of a facility ownership. It takes in account all costs of acquiring, owning, and disposing of a building or building system. LCCA is especially useful when project alternatives that fulfill the same performance requirements, but differ with respect to initial cost and operating costs, have to be compared in order to select the one that maximizes the net savings. The less are the costs foreseen for a construction solution, the better is its economical performance and more sustainable it is – within this aspect.[12]

There are numerous costs associated with acquiring, operating, maintaining, and disposing of a building or building system. Building-related costs usually fall into the following categories:

- Initial Costs—Purchase, Acquisition, Construction Costs
- Fuel Costs
- Operation, Maintenance, and Repair Costs
- Replacement Costs
- Residual Values—Resale or Salvage Values or Disposal Costs
- Finance Charges—Loan Interest Payments
- Non-Monetary Benefits or Costs

Only those costs within each category that are relevant to the decision and significant in amount are needed to make a valid investment decision. Costs are relevant when they are different for one alternative compared with another; costs are significant when they are large enough to make a credible difference in the LCC of a project alternative. All costs are entered as base-year amounts in today's dollars; the LCCA method escalates all amounts to their future year of occurrence and discounts them back to the base date to convert them to present values. [12]

The design methods of sustainable construction identify, support and recommend evolution of practices and technologies that deal with all the sustainability aspects of the sector. The evaluation methods should consider environmental pressure (related to the environmental impacts), functionality (related to the users comfort and the local building codes), social aspects (related to the social benefits) and economic aspects (related to the life-cycle costs). The fundamental object of sustainable design is a bigger compatibility between the artificial and the natural environments without compromising the functional requirements of the buildings and their respective costs. [11]

2.4. Sustainable Development and the Construction Sector

The building and construction sector is a key sector for sustainable development. The construction, use and demolition of buildings generate substantial social and economic benefits to society, but may also have serious negative impacts, in particular on the environment. Areas of key concern include energy use with associated greenhouse gas (GHG) emissions, waste generation, construction materials use and recycling, water use and discharge, and integration of buildings with other infrastructure and social systems. [4]

The building and construction sector typically provides 5-10% of employment at national level and normally generates 5-15% of the GDP. It literally builds the foundations for sustainable development, including housing, workplace, public buildings and services, communications, energy, water and sanitary infrastructures, and provides the context for social interactions as well as economic development at the micro-level. Numerous studies have also proven the relationship between the built environment and public health. [4]

The concept of sustainable construction aims at integrating the objectives of sustainable development into the construction activities. It is generally understood in relation with the environmental performance of products and assets (environmental sustainability).

The term sustainable construction as defined by Kibert (1994 in Hill and Bowen, 1997) refers to the creation of a healthy built environment using resource-efficient, ecologically-based principles. Hill and Bowen (1997) add that the term is generally used to describe a process which starts well before construction per se (in the planning and design stages) and continues after the construction team has left the site. [9]

Du Plessis (2002) describes sustainable construction as: "A holistic process in which the principles of sustainable development are applied to the comprehensive construction cycle, from the extraction and beneficiation of raw materials, through the planning, design, and construction of buildings and infrastructure, until their possible final deconstruction, and management of the resultant waste".

According to the report by the EU's Taskforce for Sustainable construction (Lead Market 2008), the concept should refer to a balanced economical, ecological and social approach. This formulation comprises three bottom-line dimensions of sustainability - or "three pillars that are people, planet and profit".

While standard building practices are guided by short term economic considerations, sustainable construction is based on best practices which emphasize long term affordability, quality and efficiency. At each stage of the life cycle of the building, it increases comfort and quality of life, while decreasing negative environmental impacts and increasing the economic sustainability of the project. A building designed and constructed in a sustainable way minimizes the use of water, raw materials, energy, land over the whole life cycle of the building.

Sustainable construction means cities and buildings that respond to the emotional and psychological needs of people by providing stimulating environments, raising awareness of important values, inspiring the human spirit, and bonding societies, communities, and neighbourhoods. [13]

The first advance within the built environment has been the development of building environmental rating systems, including the British Research Establishment Environmental Assessment Methodology (BREEAM) developed in 1990, the Leadership in Energy and Environmental Design (LEED) developed in 1993, the

Sustainable Building Tool (SBTool) developed in 2000 and Green Star developed in 2003. These systems provide a way of showing that a building has been successful in meeting an expected level of performance in various declared criteria (Cole, 2003). In addition each of these systems shares a common goal to stimulate market demands for higher environmental performance levels and they all deal exclusively with the environmental dimension of sustainability (Da Silva, 2007). [9]

The second advance has been the development of the Agenda 21 for Sustainable Construction and later the Agenda 21 for Sustainable Construction in Developing Countries. These documents provide global framework for sustainable construction with the latter acknowledging that developing countries require a different approach to sustainable construction than that used in developed countries. In addition the document targeted at developing countries aims to provide a research and development agenda and strategy for action in developing countries (CIB et al, 2002). [9]

The third advance toward *sustainable development* within the built environment has been the establishment of councils like the World Green Building Council, which (through its various member countries) seek to transform the built environment through the engagement of key stakeholders. [9]

The connection between construction practices and standards and a range of environmental quality issues is increasingly recognized. New trends in environmental accounting lean heavily towards life-cycle assessment that accounts not only for the use (energy consumption) phase of a building but also for the impacts of the pre-construction (design and siting) and construction phases. The increasingly common position that buildings, like transportation modes, should be subjected to a cradle-to-grave analyses that address the impacts of their many uses is backed by emergent data that reveals the relative environmental impacts of the various phases. [14]

Sustainability in construction projects is generally achieved by :

- Defining clear goals sympathetic to sustainability issues.
- Concentrated effort at design stage to achieve these goals.
- Focussing on decisions like site selection, building layout, design etc.
- Choosing the right materials which are recyclable after their useful lives
- Choosing the right methods of construction in terms of energy and resource efficiency
- Creating an efficient and integrated building envelope harnessing the gifts of nature
- Integrating HVFAC and electrical systems. [14]

Durability of the building depends on a variety of factors – the design, construction methods, materials, purpose of the buildings, its aesthetics and the owner. The owner is the primary determinant on the lifespan of a building and that may also be affected by current and local fashions in architecture, lifestyles and economics. In addition, new materials which are being developed for exterior cladding, roofing and to replace preserved timber are difficult to assess as their durability and suitability for construction has not been proven over the long term.[3]

Major renovations which change the design of the building will also likely occur. With office buildings, interior layouts are frequently modified to suit the corporate function and about a third of construction activities in Europe involve office refurbishment (Caccavelli and Genre). Although these renovations can be used to improve energy and water consumption and interior air quality as well as refurbishment of worn materials, they are often primarily cosmetic changes to suit the company operations. Such renovations can contribute significantly to the solid waste stream and consume resources. [3]

Over the lifespan of a building, the materials will have to be maintained and, for some, replaced. Exterior coatings, guttering, piping, walls, and flooring in particular will require repair or replacement on a 5-15 year basis. Effective maintenance can also have a significant impact on reducing requirements for replacement. The decisions here are not made by the builder or designer regardless of the original design; the owner determines what materials are going to be used for repair and how the building is maintained. [3]

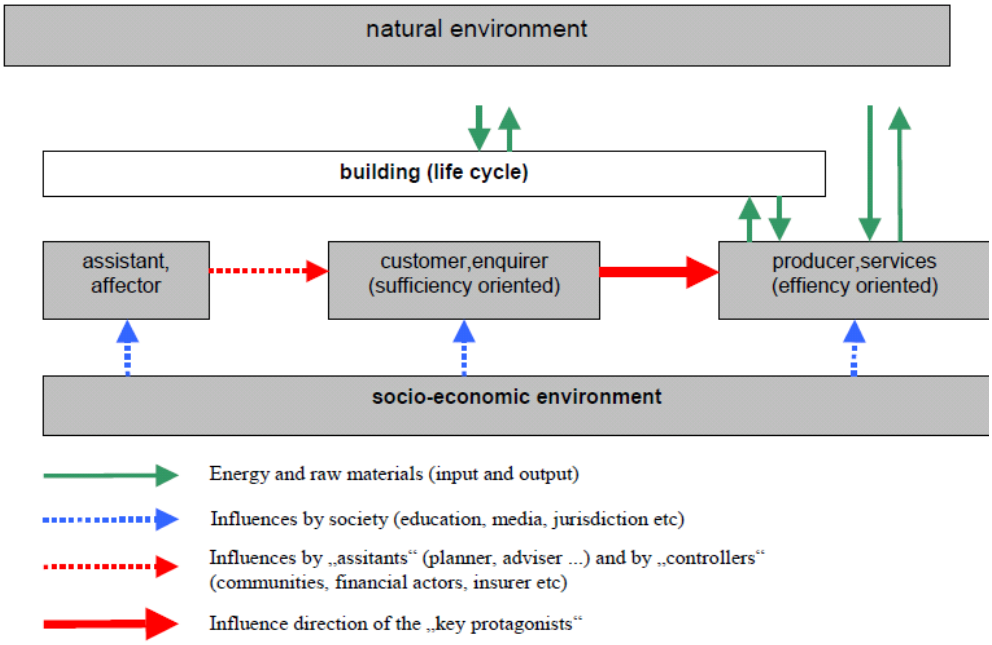


Fig. 2.12 – Influences of different factors on building durability

Regardless, both designers and builders have some influence on building durability. Good design, flexible spaces, quality materials, refraining from fashion statements which could become outmoded, all contribute to the durability of a building. However, the design and construction of many buildings today is undertaken by developers who have little interest in the long term durability of the building and are most concerned with maximizing profit over the short term. Unless developers are required to consider long term durability and quality of the buildings they produce, this short term focus will continue to be the driving factor in design and construction of most buildings. [3]

Recycled materials, while requiring transportation and reprocessing, often consume significantly fewer resources than extraction and processing of raw materials. This is particularly true for metals such as copper, iron and aluminum which can be reprocessed to a quality of that from raw material processing. Both concrete and timber can be recycled or reused but quality of the final product is often reduced. Concrete can be crushed and reused as aggregate for some purposes, particularly paving (Khati and Boyle, 1999) and mortar (Corinaldesi, Giuggiolini and Moriconi) while good grade timber can be used for making furniture.

Since it is difficult to determine whether a used timber beam has stress cracks or other weak points, reusing it as supporting timber is not always suitable. Plastic can be recycled into a number of construction products, including tiles, lumber, heating and wire insulation and carpet. [3]

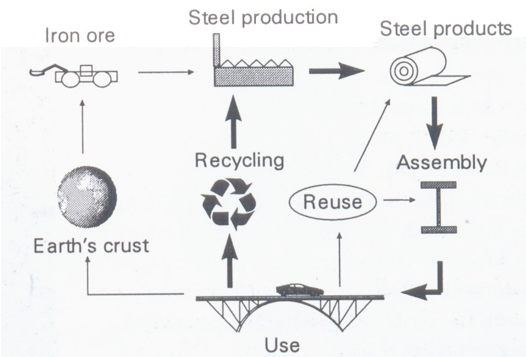
It is very important to produce buildings with a high recycling potential in order to reduce the use of energy and resources over an extended length of time. Recycling of buildings is a relatively new concept and has only been assessed in a few studies. According to an Australian study, the reuse of building materials can commonly save up to about 95% of embodied energy that would otherwise be wasted. Savings from recycling of materials for reprocessing varies considerably with savings up to 95% for aluminium but only 20% for glass. That is because some materials, such as bricks and roof tiles, suffer damage losses up to 30% in reuse.

Steel stands out as a structural material that will meet multiple sustainable building program objectives due to the highest strength to weight ratio of all structural building materials, a high recycled content and because it is a structural substitute for both dimensional lumber and reinforced concrete in residential and commercial applications.

Steel constructions can be disassembled since components are most often screwed together. After reuse, its load-bearing capacity is maintained and the product meets the original requirements for a new building. Thanks to standard dimensions for columns, girders, and light gauge steel profiles, the products are easy to identify and re-use. [39]

As framework material, only steel creates a closed cycle. This is due to the unique properties of steel: simple separation, simple recycling that has functioned for a long time, preserved high quality after recycling, and a high economic value.

All steel contains 10 - 100% recycled steel and the high quality of the material is maintained after recycling. There are two main methods of steel manufacturing: ore based production in ore and coke based ironworks with blast furnaces and oxygen steelworks, and scrap metal based production in electric arc furnace steelworks. Both production processes use raw material consisting of recycled steel. [39]



Source	Ore based production	Scrap metal based production
Recycled steel into the process	10-40%	100%
Iron ore	60-90%	0%
Percentage of world steel production	60%	34%

Fig. 2.13. Proportions of recycled steel in the production of new steel [39]

The zinc layer on a steel stud is separated from the steel, for example through a heating process where particles with zinc are filtered out and processed into new zinc. The remaining steel is melted down and used in the production of new steel. After the life cycle of a steel stud, 94-95% of the original material remains following ore based and scrap metal-based production of new steel. [39]

Insulation boards can be ordered to measure in order to reduce waste at the work site. Excess mineral wool in the form of waste at the assembly site can become raw material for the production of mineral wool that can be used as loose filling in attics in the area. New glass fiber is produced using 75% recycled material where recycled glass constitutes 65 percentage units and waste 10 percentage units. New rock wool is produced from 50% production waste and blast furnace cement, a residual product of iron production. [39]

Manufacturing Process	Domestic Industry Data	Basic Oxygen Furnace	Electric Arc Furnace
2006 Annual Domestic Production (tons)	105,928,500	46,802,100	59,126,400
Percent Domestic Production by Process[A] (%)	100.00%	44.18%	55.82%
Recycled Steel Used in Production	43.08%	12,631,400	33,005,200
Recycled Content (tons)[A]	Post-Consumer	10,534,588	27,526,337
	Post-Industrial	2,096,812	5,478,863
Recycled Content (%)	Post-Consumer	22.51%	46.56%
	Post-Industrial	6.19%	26.93%

Tab. 2.4 Recycled Content of Domestic Steel
Source: Steel Recycling Institute, 2006

Gypsum wallboards also have a functional closed cycle. In the production of new gypsum boards, 0-10% recycled gypsum products are used today. The remaining portion consists of 10-50% natural gypsum and 40-90% industrial gypsum. Industrial gypsum raw material is a residual product from, for example, air purification. It is possible to use up to 15 % of recycled gypsum in the production. Recycled gypsum can also be used for other purposes, for example for fertilizers.[39]

Environmentally sound construction must primarily involve measures that prevent the production of waste products instead of having to deal with them. The cost of delivering the exact right amounts to a construction site is lower than the cost of dealing with the waste. Today, what is costly is the work of collecting such waste. Steel is a very stable and durable material. This means that a smaller amount of steel is required than wood or concrete in order to fill the same function. Since steel also is a very exactly dimensioned material, it can be supplied in exact lengths with no waste. Normally, the percentage of prefabrication is also high. [39]

Few components facilitate waste management. A building must also be easy to dismantle and the materials must be easy to sort. Steel, mineral wool, and gypsum board can be dismantled and are adapted to a closed cycle with a functioning recycling system

Of course, it should also be kept in mind that the single most important factor in reducing the impact of embodied energy is to design long life, durable and adaptable buildings (Milne 2005). By extending the life span of a building, the energy and costs associated with demolition and construction of new buildings are deferred until later. [3]

The commencing of sustainable construction at the planning and design stages, suggests that architects have a vital role to play in the development of a sustainable built environment. This is because they predominately have the initial and most frequent contact with a client and have the direct access to all the professional team members, as well as the contractor. They are obliged to provide creative thinking, be at the cutting edge of technology, exercise strategic management skills, and be skilled craftspeople in order to conceptualise and manage the delivery of the physical infrastructure (CSIR, 2003). [15]

In addition to the need to continue performing their architectural duties, architects are expected to familiarise themselves with the issues of sustainable development and to ensure that they are competent at designing infrastructure in a sustainable manner (CSIR, 2003). [15]

Architects need to be the first professionals to ensure that the principles of sustainability are adopted into design projects (Edén *et al*, 2003). The current involvement of other built environment professionals, particularly engineers, at a stage where the brief has been defined and the design concept developed, demonstrates, according to Willis (2000), that for architects, aesthetics plays an important role as their commitment to a particular built form gives the impression that sustainability is an afterthought. [9]

In order to ensure that building performance is sustainable, any ambitions to contribute to sustainability should be dealt with in the initial stage. Furthermore, the professional team and the contractor should be involved in the development of the formulation of the client's brief in such a way that this "locking" process takes advantage of the participators' competence and local prerequisites (Edén *et al*, 2003).

The architect's role within the built environment is crucial in the implementation of sustainability. This is because the planning and design phases are the most critical as this is where environmental impact of the building is highest as no construction has not occurred and limited project costs spent. [15]

In conclusion, buildings should be designed with due consideration to factors such as local climate, transport distances, availability of materials and budget, balanced against known embodied energy content. When choosing a building material, these guidelines should be followed:

- Design for long life and adaptability, using durable low maintenance materials;
- Ensure materials can be easily separated;
- Avoid building a bigger house than needed. This will save materials;
- Modify or refurbish instead of demolishing;
- Ensure materials from demolition of existing buildings, and construction wastes are re-used or recycled;
- Use locally sourced materials when possible (including materials salvaged on site) to reduce transport;
- Select low embodied energy materials (which may include materials with a high recycled content) preferably based on supplier-specific data;
- Avoid wasteful material use;
- Specify standard sizes, don't use energy-intensive materials as fillers;

- Ensure that off-cuts are recycled and avoid redundant structures. Some very energy intensive finishes, such as paints, often have high wastage levels;
- Select materials that can be re-used or recycled easily using existing recycling systems;
- Use efficient building envelope design and fittings to minimize materials (e.g. an energy-efficient building envelope can downsize or eliminate the need for heaters and coolers, water-efficient taps allow downsizing of water pipes, etc);
- Ask suppliers for information on their products if not provided. [4]

The high investment costs involved, the lack of information on energy-efficient solutions at all levels, as well as the (perceived or real) lack of availability of solutions to specific conditions, are considered as the major barriers to implementing sustainable principles in the building industry. In addition, there can be a number of organizational barriers, such as different decision making levels, privatization - deregulation processes, different stakeholders deciding on the structural system and energy consumption, etc. [4]

It is clear that there are no universal solutions for improving the sustainability of buildings. General guidelines must be adjusted to the different climate, economic and social conditions in different countries. The local availability of materials, products, services and the local level of technological development must also be taken into account. [4]

Since the publication of the Strategy for Sustainable Construction in June 2008, the world's economy has suffered a significant set-back and the financial conditions now prevailing are very different. The construction industry is not immune. Organizations will need to respond to the challenges which are still emerging, through the maintenance of a healthy and skilled workforce and supply chain; by adhering to the tenets of corporate responsibility; and by incorporating environmental considerations into every facet of operations. This will all contribute to a financially, socially, and environmentally sustainable construction sector ready to meet the upturn in a stronger position than before. [16]

2.5 Conclusions to Chapter 1

Maintaining a balance between developing the built environment and protecting the natural environment is at the core of sustainable construction. This balance can only be achieved if the construction industry shifts from the traditional linear process of production (material excavation → production → waste) to a cyclic process by increasing the use of renewable and recycled materials (Miyatake, 1996, Du Plessis, 2002). For instance, as reported by Mora (2005), the construction industry is responsible for 7% of global CO2 emissions which is mostly due to the production of concrete (approximately 1 kg of CO2 for each kg of cement produced); this concrete is usually ending as waste dumped in landfills.

Therefore, "sustainability would only be possible when construction uses renewable energy resources, and renewable materials or materials recycled from construction waste" (Mora, 2005, 1333). In addition, a new revolution in resource efficiency is needed through focus on the reduction of raw materials extraction and the minimisation of waste generated (Macozoma, 2002). It is worth noting that the impact of construction waste is not only limited to the environmental pillar of sustainability. Waste has a social and economic impact as well. In fact, improving the way with which the natural resources are used can help to achieve cost savings and to generate new opportunities and jobs (DEFRA, 2007).

A 2009 report by the U.S. General Services Administration found that sustainably designed buildings cost less to operate and have excellent energy performance. In addition, occupants were more satisfied with the overall building than those in typical commercial buildings.

Achieving sustainable development will be a long journey, spanning many decades. It will require nothing less than a complete overhaul of our existing systems, technologies and infrastructure, replacing them with approaches that are less energy and resource intensive, use less toxic materials, and protect the environment and society. All this must be accomplished in a manner that is workable in both developed and less developed countries.

3. Sustainable Low Rise Residential Construction

3.1.Introduction

Starting with general considerations on the specifics of low rise residential design and its interconnectivity to market constraints, the analysis is then extended to the challenges and trends characteristics of residential architecture today.

The overview of the evolution of residential layouts shows a constant tendency to increase house sizes and the gradual move from compact to open plans.

This chapter aims to position steel framed houses, within the larger context of low energy building.

Low energy houses represent the construction sector's response to the challenges of sustainable development. Different types of low energy houses are presented. Within this larger context, we find various types of steel framed houses.

3.2. Specifics of Low Rise Residential Design

In what follows we will look into some architectural design aspects specific to residential design, aspects that have a lot of bearing on the design process, starting from the conceptual phase, all the way to project completion.

Architectural design is often defined as „ a concept that focuses on the components or elements of a structure or system and unifies them into a coherent and functional whole, according to a particular approach in achieving the objective(s) under the given constraints or limitations." [30]

Low rise residential designs, when properly addressed, tend to be quite complex, despite the typically small project dimensions, when compared to other architectural programs.

We have to stress out again that, in this thesis ,we are referring, to the "average" sized house and that the occasional extravagant examples are presented for their specific characteristics only.

Typically, a complete a residential design package shall include the following components :

Architectural and Interior Design

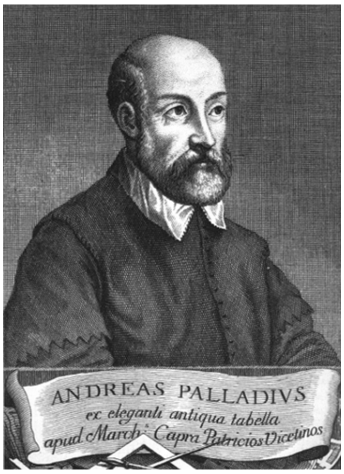
Structural Engineering

Electrical and HVAC

Landscape Design, another important component of residential design, interconnected to both architectural and interior design packages, will be not addressed here.

The principles of integrated design and the specific contributions of the engineering components will be discussed further in Chapter 5.

The evolution of house design is inextricably linked to the history of human race. From the so called primitive hut to Palladio's villas and the present day ecological house, the road encompasses probably more than 50 000 years.



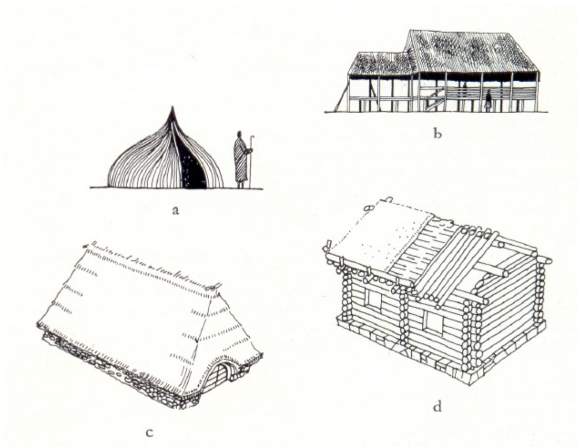


Fig. 3.1 Andrea Palladio *Evolution of human settlement [33]*

Low-rise residential buildings include the smallest buildings produced in large quantities. Single-family detached houses, for example, are in the walk-up range of one to three stories and typically meet their users' needs with about 90 to 180 square meters (about 1,000 to 2,000 square feet) of enclosed floor space. Other examples include the urban row house and walk-up apartment buildings. Typically these forms have relatively low unit costs because of the limited purchasing power of their owners. [35]

Fig. 3.2 Many members of the lower middle class in the Midwest and South live in post-WWII homes such as this one in Hazel Park, Michigan.

The demand for this type of housing has a wide geographic distribution, and therefore most are built by small local contractors using relatively few large machines (mostly for earth moving) and large amounts of manual labour at the building site. The demand for these buildings can have large local variations from year to year, and small builders can absorb these economic swings better than large organizations. The building systems developed for this market reflect its emphasis on manual labour and its low unit costs. [35]

A proportion of single-family detached houses are "factory-built"; that is, large pieces of the building are prefabricated and then transported to the site, where considerable additional work is required to complete the finished product.

Such a vast subject was, it is and will always be a living source for countless interpretations. Bernard Rudofsky, in his exhibition and book manifesto "Architecture without Architects", depicts the long becoming of human settlements, within their specific regional settings, starting from the basic, reproducible unit.

Throughout history the non-pedigreed architecture was the product of anonymous builders. Today, even though legislation throughout the world requires or encourages the participation of an architect in house design, the overwhelming majority of built low residential is made with minimum input from qualified designers. The proliferation of house plan catalogues and their availability through the internet, oversimplifies the decision process and is largely responsible for the questionable quality of architectural objects and new developments as a whole.

Fig. 3.3 House in Eforie, Romania

Fig. 3.4 House near Timisoara

According to Vitruvius, a good building should satisfy the three principles of *firmitas, utilitas, venustas*, which translate roughly as :

Durability – it should stand up robustly and remain in good condition.
Utility – it should be useful and function well for the people using it
Beauty – it should delight people and raise their spirits

Staying within its self-imposed boundaries, this thesis looks only into those sets of conditions which seem to determine, *objectively*, building design decision making, i.e. *firmitas* and *utilitas*. This thesis does not investigate aspects linked to *venustas,* the philosophical and aesthetic principles and concepts which feed architectural thought.

These old Vitruvian principles can be interpreted to include the concepts of sustainability:

- Commodity, usually understood as fitness for use, is broadened to mean effectiveness, in environmental, economic, and programmatic terms.
- Firmness, surpasses structural reliability and incorporates long term environmental sustainability, comfort, and longevity.
- Delight, moves beyond pleasure in aesthetics and embraces deeper meaning.

Indeed, it appears that throughout history the equation changed very little. Man was always forced to find a quick answer to the riddle :

What needs can be satisfied with what available resources and in which way.

One of the most important characteristics of low rise residential buildings, is the coexistence, in the same object of both architectural and interior design elements.

Indeed, in successful designed and executed buildings, it is quite impossible to draw the line between the two, as it happens for example in Gio Ponti's masterpiece Planchet House, or Gerit Rietveld's famous Schroder House.

Fig. 3.5 Gio Ponti - Planchart House, Caracas

Fig. 3.6 Gerrit Rietvel- The Rietveld –Schroder House interiors

Selection of all interior finishing materials, kitchen and bathroom design, as well as furniture and accessories selection, are all integrant part of a residential project and are usually considered part of the interior design package. The interior design component represents about 25% of the construction budget, for the average house, out of 35-40% total finishing.

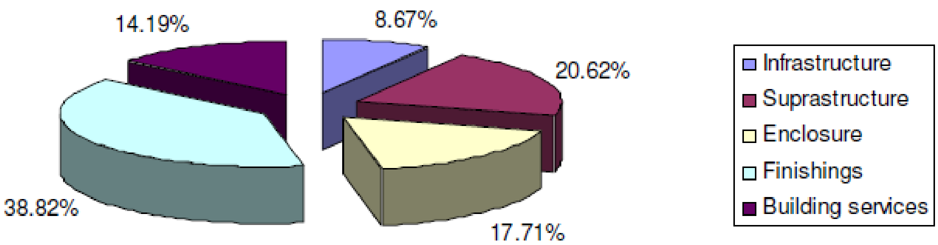


Fig. 3.7 Distribution of construction budget by building component

This implies that either the architect takes charge of the interior component or an interior designer is commissioned to complete the design work, in order to deliver a complete package.

Discussing such practical aspects is important given the fact that more often than not, house design packages are not complete, due mainly to low project fees common for most projects, with the result of reduced building quality.

The price tag of an average house equals that of a very sophisticated car, though the amount of technology, detailing and craftsmanship is usually superior in the latter. It appears that in order to be able to balance good quality design with limited design and construction budgets, some form of reproducible patterns have to be taken into account, with the effect of producing short series of buildings.

Mass production is not really an option, with the exception perhaps of building components, such as roof trusses, etc.

Housing construction has undergone many variations over the years, evolving to meet economic, environmental and social considerations at different times. Floor plans and styles are developed to meet latest trends and fashions, while the choice of construction materials may be guided by reasons ranging from cost to conservation considerations.

Home builders and buyers need to make numerous decisions about the materials and fittings they will use and the designs they will choose when planning every aspect of a new home. The planning stage is the ideal time to consider aspects such as health and safety as well as cost and appearance. The materials chosen for behind the walls, in the roof space and underfoot are once-only decisions.

Although many historic materials are still in use—roofs are still constructed of copper and slate, and walls employ natural stone—the building envelope has been a prime target of innovation since the first quarter of the twentieth century. Innovation has been most significant in the wall and fenestration systems of the envelope and has been driven by four main influences:

- Cost reduction for a competitive market
- Enhanced performance
- Material innovation and industrial research & development
- Aesthetics

These influences are all related to one another. Much industrial research and development has been aimed at obtaining a competitive edge through performance improvement or cost reduction. For example, pre-cast concrete fabrication enjoyed about two decades of great success because the material and shapes appealed to architects. Innovation in pre-casting techniques, form design and fabrication and surface finishes resulted from collaboration with architects and the effort to be competitive as a supplier. Ultimately, however the pre-eminence of the pre-cast panel facade was seriously threatened by the rise of glass fibre reinforced concrete, a synthetic material innovation that was lighter and more economical than concrete and more easily formed into sculptured shapes.

The construction industry is intensely competitive. Much of this stems from the traditional approach to contractor and supplier selection—the competitive bid. This places a premium on lowest cost, resulting in innovation by contractors and sub-contractors trying to get an edge on their competitors. Another aspect of cost is that of reduction in construction time, which translates into cost reduction for a building project's entire stakeholder. Thus, for example, the separation of the building envelope wall and fenestration from the structure enabled the structure to be erected faster, while prefabricated components such as curtain wall assemblies and pre-cast panels were fabricated off-site.

3.3. Residential Architecture Layout Evolution

The use of steel framed structures for residential purposes goes back, as shown in Chapter 3, to the first half of the 19th century, at the time when, mostly in England, the search for better living conditions for the lower and middle classes, became a central objective for a wide range of individuals interested in society's progress, ranging from industrialists to royalty, philanthropists and architects.

To exemplify this prevailing mood, it is worthwhile to look into the making of the two model houses for the Universal Exhibition of 1850 in London.

Henry Roberts (1803-1876), a founding member of the Institute of British Architects (1835), was best known as a champion of providing the working classes with decent living accommodation. In 1844 he became a founding member and honorary architect of the Society for Improving the Condition of the Labouring Classes. At that time, the living conditions of most working people in the UK were appalling, particularly in the inner cities. It was common to have families of eight or more living in a set of two rooms, with communal lavatories and open sewers. Access to clean water was often limited to a shared cold water tap in a lobby, or a communal pump.

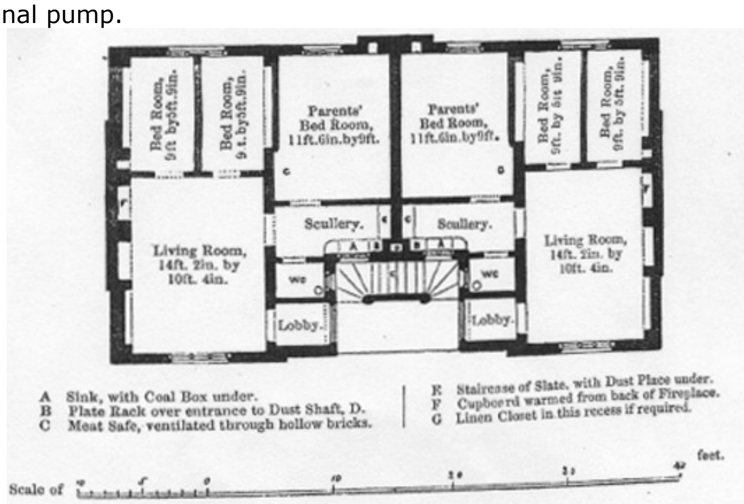


Fig. 3.8 Henry Roberts - Model house plan, 1850, London

The SICLC, with Prince Albert as the first president and the Earl of Shaftesbury as vice-president, was the leading light in a successful campaign to abolish taxes on windows and bricks, the main stumbling blocks to the development of social housing in the 19th century. Roberts also invented a hollow brick that not only brought the costs of construction down, but also improved insulation and made the building of walls more efficient.

In 1851 the SICLC erected two model houses designed by Roberts in Hyde Park for the Great Exhibition of 1851. Prince Albert was closely involved in the design and financing of the houses.

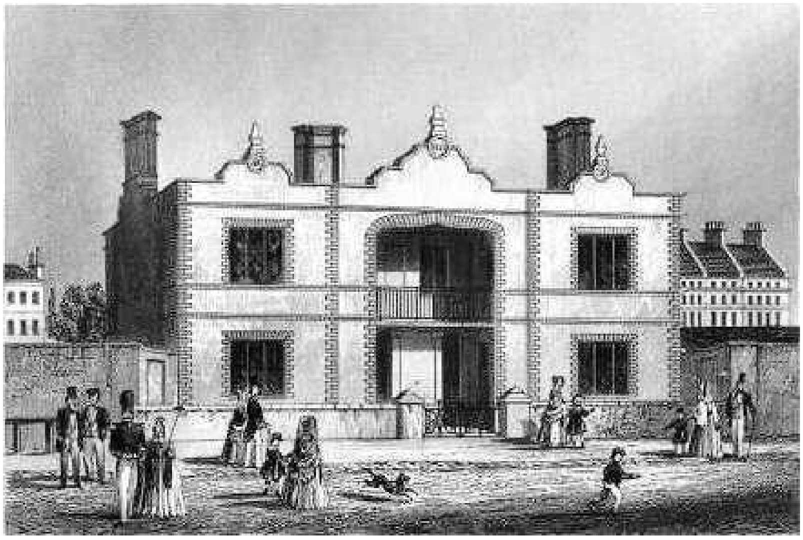


Fig. 3.9 Henry Roberts - Model house front view, 1850, London

Each house was designed to accommodate four families in separate flats. Each flat was provided with running water and internal sanitation, with a separate kitchen area (or scullery) and three bedrooms, essential for the large families of the day. The construction of the house was simple, robust and economical as well as being attractive to look at. After the Great Exhibition closed, the building was dismantled and re-erected at Kennington Park, where it still stands today.

As the purpose of this thesis, is to demonstrate the advantages of using steel structures in low rise residential buildings, it is interesting to look at the evolution of house layouts, as influenced by the evolution of living standards and of the functional requirements.

Indeed, a noticeable evolution on architectural layouts, for the average sized house, can be associated with the advent and development of Modern Movement in architecture.

House floor plans are determined in the first instance by lot shapes.

The evolution of lot sizes is a vast subject, well beyond the goals of this thesis. Nevertheless, the evolution of lot and house sizes is evident.

In America, lot sizes began to grow after the turn of the century.

Early 20th century bungalows were one-storey or storey and a half dwellings of between 600 and 800 square feet. In most new houses of the early twentieth century, square footage was drastically reduced to compensate for the increased expenses of plumbing, heating, and other technological improvements... Housing studies also related the reduced square footage to the decline in domestic production of goods. There was no longer a need for places to store away quilts, home-canned vegetables, and dowry linens for future use. People were no longer producers, but consumers.

Bungalows in the 1940s had lots measuring 60 by 100 feet.

The first North American homes were very small, one room, one-storey structures that were based on European building techniques brought by settlers and eventually adapted to the building materials, climatic conditions, and topography of the New World. The majority of these structures had less than 450 square feet of space, but were eventually remodelled and expanded over time. Through the middle years of the 18th century, older houses everywhere were added to and vigorously remodelled, with room heights rising a foot or more, and parlours added in the homes of ordinary well-off farmers and other gentry.

At the beginning of the last century, in the United Sates, for example, the average home was 700 to 1,200 square feet. In 1950 the average home was 1,000 square feet growing to an average size of 2,000 square feet in 2000. An interesting fact revealed in the [National Association of Home Builders (NAHB)] report is that the average lot size will shrink by another 1,000 square feet while the house size will increase to 2,200 or more square feet. [34]

The evolution in time of human needs and of family structure determines the configuration of house layouts, from the most primitive shelters to the technologically advanced.

Layout evolution parallels the history of architecture and shows a constant preoccupation to balance out needs and resources.

As far back as the Cucuteni Neolithic culture, the primitive huts presented already two types of spaces, one for preparing and consuming food, and the other for gathering and sleeping. These two basic functional requirements, made their way up to our times.

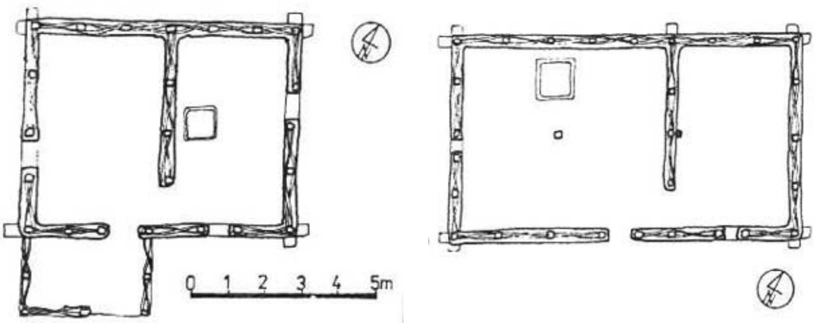


Fig. 3.10 Habasesti - jud. Iasi, Neolithic cca. 3500 - 2500 î.Ch., Cucuteni "A"

As mentioned already, layouts are determined by lot shapes and sizes.

The single detached house has therefore the tendency to have a more rectangular or even square shape in contrast to the row houses, which have to be accommodated in relatively narrow lots.

The single detached house, evolved in various cultures from local dwelling tradition.

By 1785, a well to do household in Ploiesti, presented already a more elaborated layout, developed from much simpler peasant houses. Even so, the typical partition of the layout, between production and representation is clearly evident.

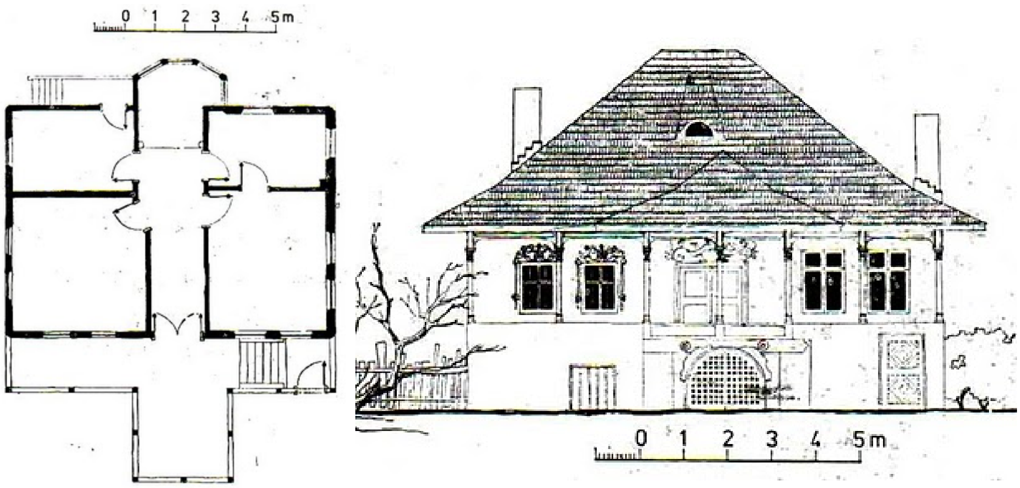


Fig. 3.11 Hagi Prodan House – Ploiesti 1785 – Grigore Ionescu

In the New World, the vast space available, and the thinking associated with the development of the American continent, led to a number of new house planning principles. A. J. Downing, the noted landscape designer and writer, saw in the cottage the answer for future housing developments.

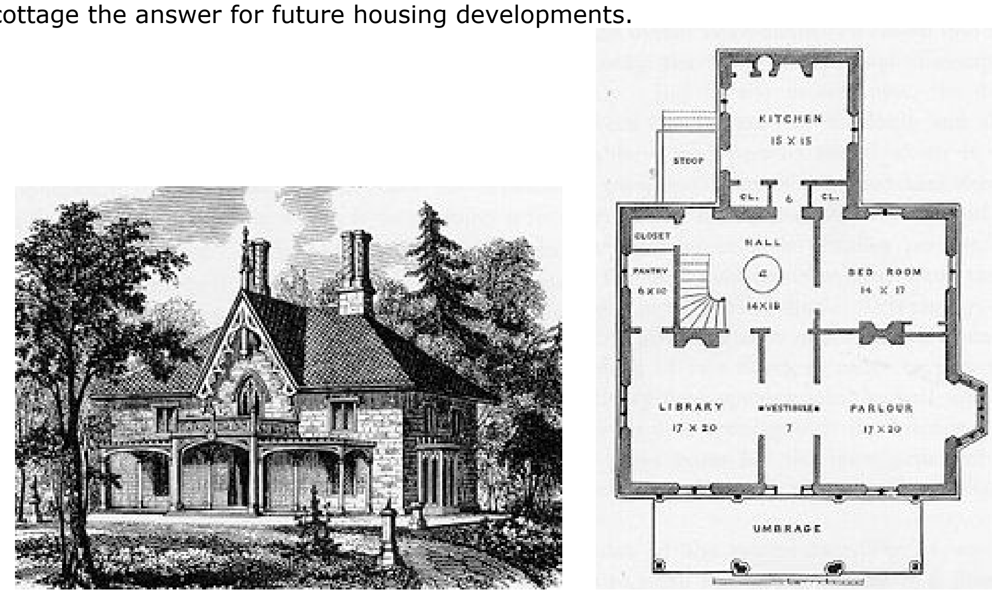


Fig. 3.12 A.J. Downing- English or rural gothic style cottage

In the work of A.J. Downing, the idealized cottage designs, show a clear preoccupation for the introduction of new living spaces, in order to enhance family life.

Downing's building designs were mostly for single family rural houses built in the Picturesque Gothic and Italianate styles. He believed every American deserved a good home, so he designed homes for three types: villas for the wealthy, cottages for working people and farmhouses for farmers.

Downing believed that architecture and the fine arts could affect the morals of the owners, and that improvement of the external appearance of a home would help "better" all those who had contact with the home. The general good of America was benefited by good taste and beautiful architecture, he wrote. Downing saw that the family home was becoming the place for moral education and the focus of middle class America's search for the meaning of life

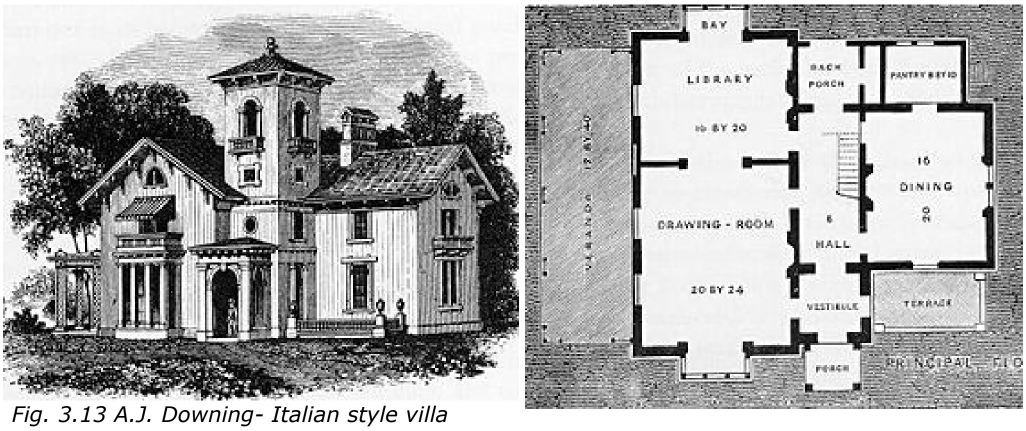


Fig. 3.13 A.J. Downing- Italian style villa

Meanwhile, in the British Islands, Victorian society was short of space, therefore, a good house meant generally a terraced house. Jackie Craven’s account of a typical 1900 Victorian terraced townhouse located in Greenwich, London, is most telling in this respect.

In the cities, small row houses went up in great numbers in the first half of the century, virtually all with parlours. The average urban row house was narrow, usually only 15-20 feet across, extending back for 30-40 feet. With the mounting pressure for effective land utilization, row houses became narrower and deeper over time; two 25 feet lots were divided into three. [65]

Some large homes existed, as well, in the 1800s, some ranging between 2200 and 2800 square feet, which is about the size of a good-sized suburban home today. [65]

During the 19th century, the different functions of the house were compartmentalized into separate areas. The public and private rooms were kept apart. As with most other rooms, the bedroom was largely an invention of the late 18th and early 19th centuries. Until then all but the most privileged colonists lived in one or two rooms and beds stood throughout their homes. [65]

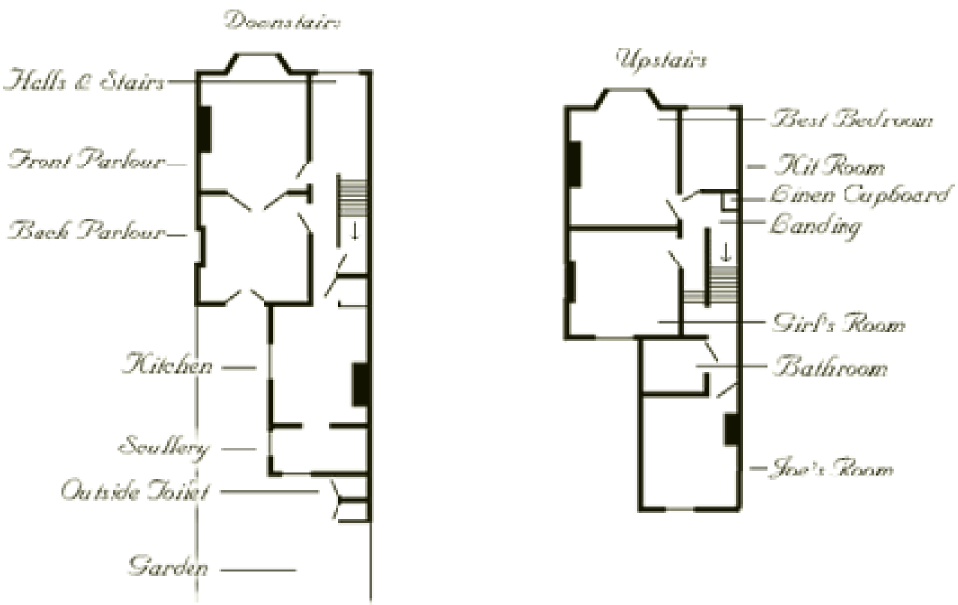


Fig. 3.14 Victorian house - floor plans

Front Parlor

The largest room in the 1900 house was more for looking than living. The front parlor was the reception hall and the showplace. Here, vases, statuettes and other decorative items which symbolized the family's status were displayed. [65]

Back Parlor

The smaller back parlor served as the recreation and dining room. In this small space, the entire family assembled for games, conversation, music and meals.

Kitchen

The kitchen was the control center of the home. Here food was prepared and important household business was conducted. The coal burning range was the central heat source heat for the household. In keeping with its importance, the kitchen was as large as the parlor. [65]

Scullery

The scullery was a small room adjacent to the kitchen. It held the "copper" for boiling clothes and other cleaning equipment. In 1900, cleaning was a long and laborious task, and even modest households often hired servants to work in the scullery. [65]

Bedrooms

They were not created to accommodate reading, exercise or other recreational pursuits. Small and dimly lit, they would not hold today's queen sized beds. Children shared rooms, sometimes piling into a single bed. [65]

Bathrooms

In Victorian times, the bathroom was a status symbol. Only well-to-do families had a tub, and a toilet was rarely installed inside the house. In this floor plan, the bathroom is a small second floor room appointed with a tub and a washstand. The toilet is housed in a closet-sized shed, outside behind the scullery.[65]

The living conditions typical for the large majority of Victorian society, depicted above were common to most of the Western middle class.

Fig. 3.15 Tony Garnier, dessin pour une cité-jardin

By the turn of the century the generally used construction method for low rise residential was brick masonry with reinforced concrete frame. That allowed for larger spans, typically up to 5m and led to more squarish layouts determined by both structural design and lot shapes. Single detached buildings became more and more popular, as can be seen in the designs of Tony Garnier for the ideal middle class city.

Another major influence on the evolution of architectural layout came from the new manner architects thought of building mass, phenomenon associated with the *Cubist Movement* in visual arts.

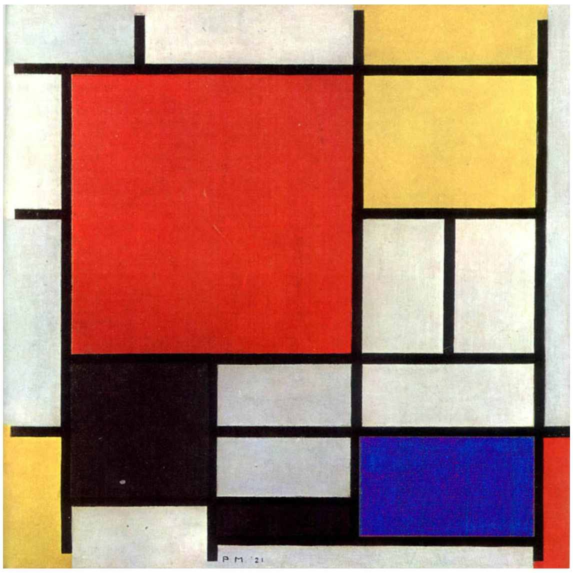


Fig. 3.16 Piet Mondrian - Composition

The all prevailing mood of renewal in visual arts characteristic of the times, is beautifully summoned up by Kazimir Malevich:

"I have transformed myself in the zero of form and fished myself out of the rubbishy slough of Academic Art. I have destroyed the circle of the horizon and escaped from the circle of objects, the horizon-ring that has imprisoned the artist and the forms from nature. The square is not a subconscious form. It is the creation of intuitive reason. The face of the new art.

The square is the living, royal infant. It is the first step of pure creation in art."

--Kazimir Malevich, from "From Cubism to Futurism to Suprematism: The New Realism in Painting"

Architects started to explore the plastic resources of the cubic form and adapted gradually layouts to fit compact volumes. This sketch by famous Viennese architect Adolf Loos, is indicative of this trend.

Fig. 3.17 Adolf Loos – Muller House Architectural Sketch

The influence of the Cubist Movement was quite determinant on the evolution of the Bauhaus school. This axonometric study by Walter Gropius portrays a new phase of the relationship painting-architecture, in which architects, already convinced by the plastic wealth concealed in the new form of expression, were busy rationalizing and finding functional solutions for their designs.

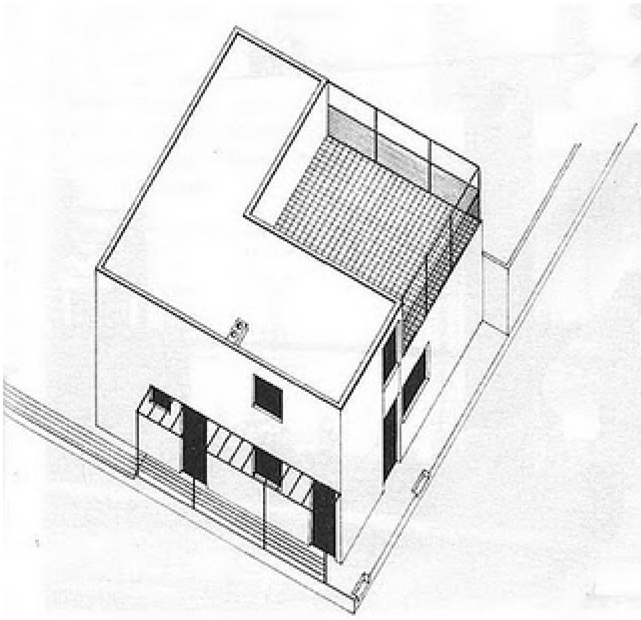


Fig. 3.18 - House No 16, Walter Gropius, Weissenhof, 1927

Fig. 3.19 Walter Gropius House, Bauhaus

By the end of 19th century, Great Britain was the most important industrialized nation, and for many architects, as for example J.P.P. Oud and Adolf Loos, it represented the utopia of the middle class, of which articrafts were characterized by innovation, quality and practicality.

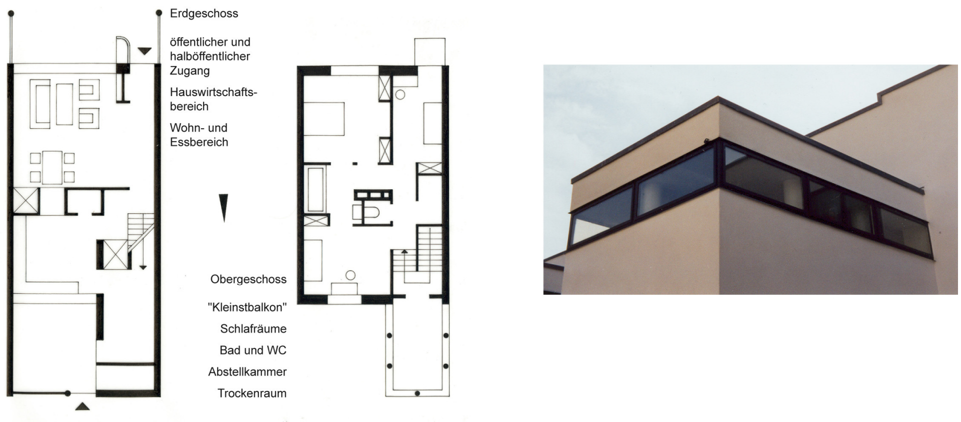


Fig. 3.20 JPP Oud -Weissenhof Row Houses · Stuttgart, Germany

Despite early criticisms of the Werkbund as merely fashionable and wasteful, Adolf Loos agreed to take part in the 1932 exhibition to design a row of houses for working class housing. The exhibition was designed to show 'the maximum exploitation of space'. Loos had been appointed as chief architect for the housing department of the city of Vienna in 1921 but resigned in 1924.

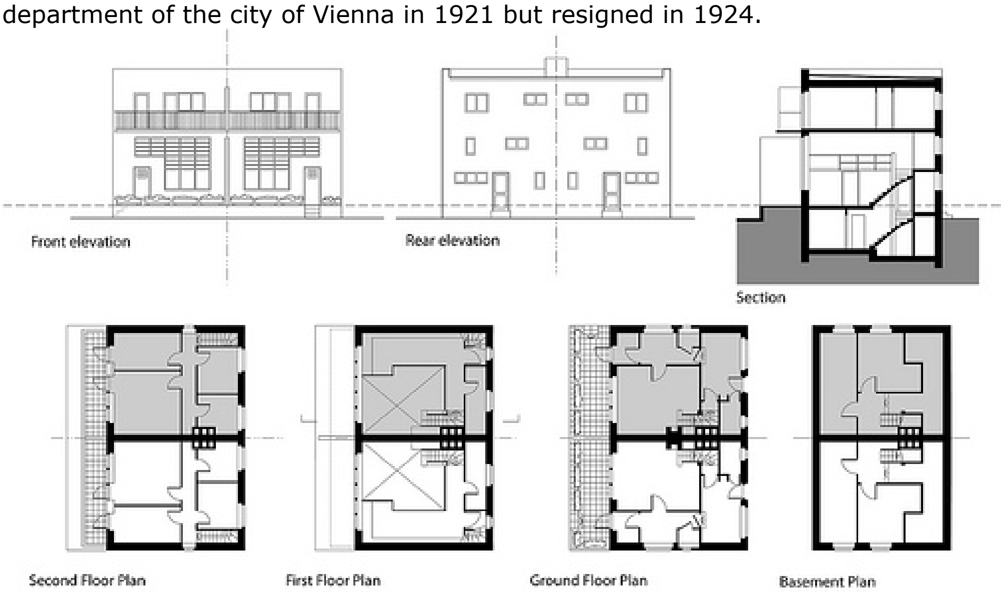


Fig. 3.21 Adolf Loss, Vienna 1932

The Werkbund houses account for two pairs of semi detached dwellings, although small still display Loos characteristics in the form of the double height living and dining space overlooked by a gallery with study desk. There are bedrooms on the top floor with a large balcony to the front aspect, and a cellar at basement level. The utilitarian appearance with flat unadorned surfaces, large south facing windows and cubic volumes were common themes and aesthetics at the exhibition.

The design is based upon the Scheu house of 1912 which was conceived as a series of interconnected volumes or spaces with the main stair housed in a large high ceilinged hallway and roof terraces outside the bedrooms on the upper floors.

In Romania, the search for better living conditions for the lower and middle classes led to model housing projects, like the "Vatra Luminoasa" subdivision. Despite the relatively small dimensions, the houses have a very rational plan layout.

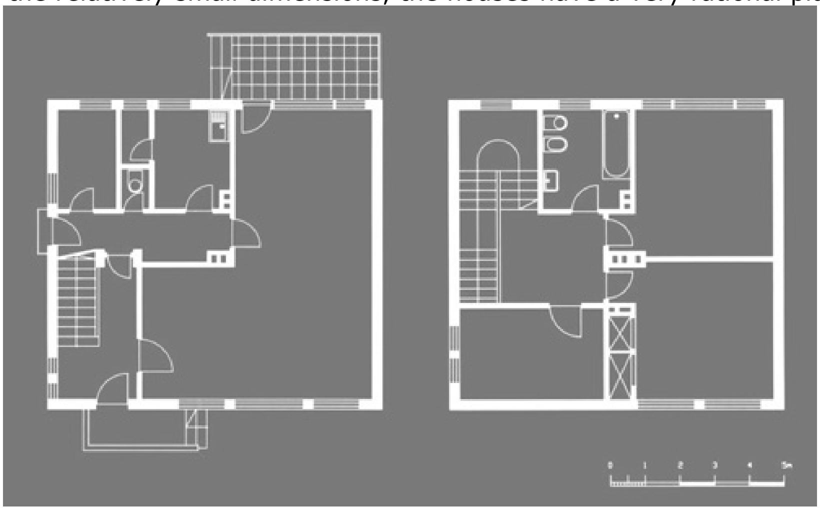


Fig. 3.22 Arh Ion Hanciu proiect Vatra Luminoasa, Bucuresti

The evolution of architectural layouts in Romania in 1930's, can be best illustrated by the work of noted Romanian architect Horia Creanga, credited to be the most talented and prolific designer of his generation.

From the Mateescu House, with a layout solved within the constrains of the rectangular shaped plan, to the more dynamic and flexible floor plan achieved in

Fig. 3.23 Horia Creanga, Vila Mateescu, Bucharest, Romania

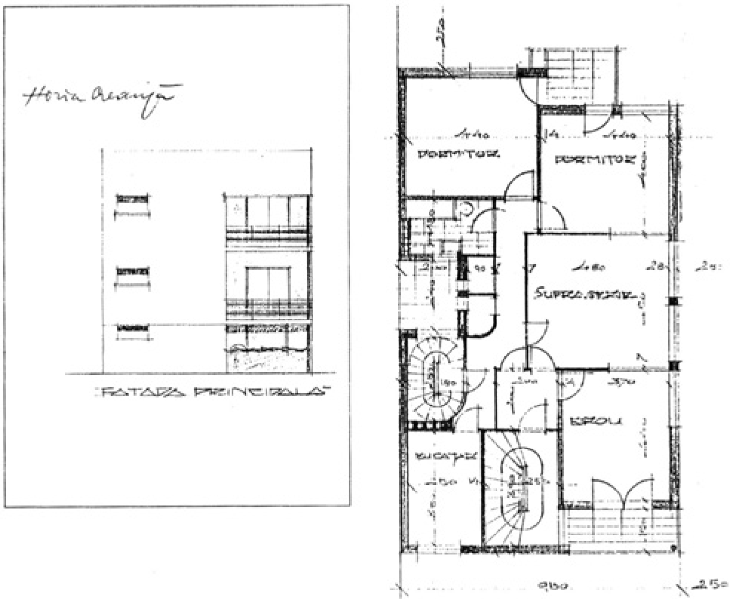


Fig. 3.24 Horia Creanga, Vila Mateescu - plans, Bucharest, Romania

Casa Bunescu, built in Bucharest in 193.., one can see the constant preoccupation of the architect to free the plan, within the structural limitations of reinforced concrete frame and masonry wall structure.

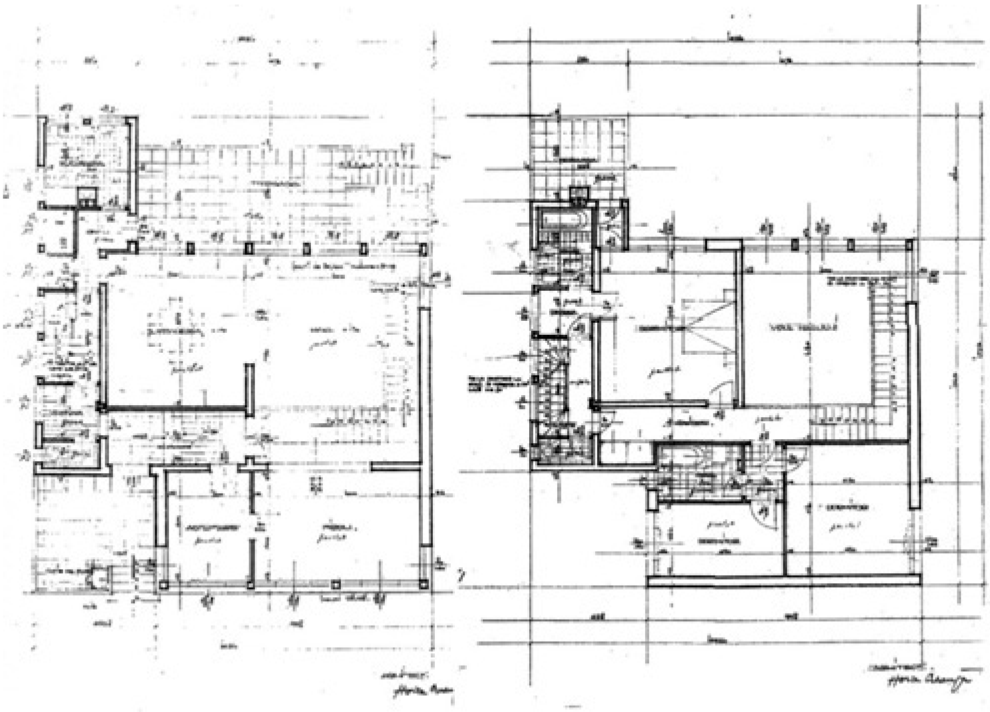


Fig. 3.25 Horia Creanga, Vila Bunescu

3.4. The Open Plan - Layout Flexibility

The great masters of modern architecture, Frank Lloyd Wright, Mies van der Rohe, and Le Corbusier, each had his distinctive version of the free plan and each his characteristic version of furniture placement.

Historically, the open plan in the Western World is usually traced back to the Robie House project by Frank Lloyd Wright, built in Chicago in 1909. The most refined produce of the Prairie Houses, the Robie House illustrates all of Wright's new architectural concepts which were to influence the entire modern architecture.

Wright characterized his struggles away from the closed rooms of traditional planes as an effort to be free of being "boxed, crated", and said he "first consciously began to try to beat the box in the Larkin Building – 1904". [66]

The mixed brick masonry – steel girders structural system allows for large spans and overhangs which accentuate the horizontal dimension of the house. The corners of the volume are freed to accommodate windows.

Fig. 3.26 - F. L. Wright- Robie House, Chicago

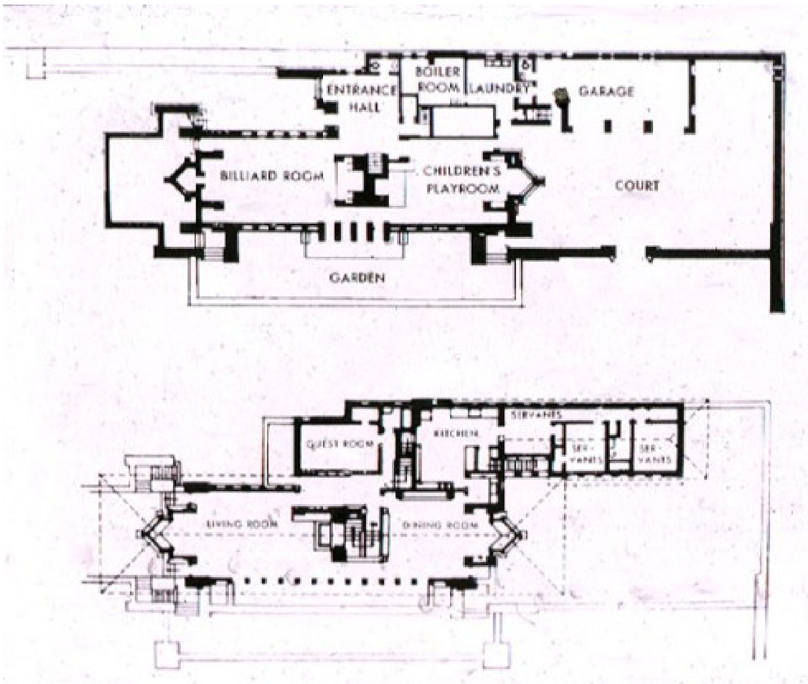


Fig. 3.27 - F. L. Wright- Robie House, Chicago - plans

The influence of this design on the whole modern movement was tremendous and the introduction of steel frame structures in the 30's allowed architects to further expand this concept.

Fig. 3.28 Le Corbusier - Villa Savoye, Poissy, 1931

The Corbusian free plan is opened to the world outside primarily through horizontal ribbon windows, there being a palpable wall enclosing the interior. The world inside this wall is not part of the universe, as is in Mies' world, nor part of the surrounding landscape, as is Wright's, but a hermetic domain of its own. Unlike Wright's plan, there is no centre of gravity here, rather, all elements – walls, floors and ceilings, cabinets and doors, tables and chairs – are bound up in a three-dimensional composition that is thoroughly, idiosyncratically Corbusian. While the placement of these elements is, as Le Corbusier advertised, free of the building structure, his *plan libre* is not as radically open as that of Mies. [66]

Richard Neutra was one of the architects who explored further Wright's direction and who designed some of the most spectacular houses in America in the 30's and 40's.

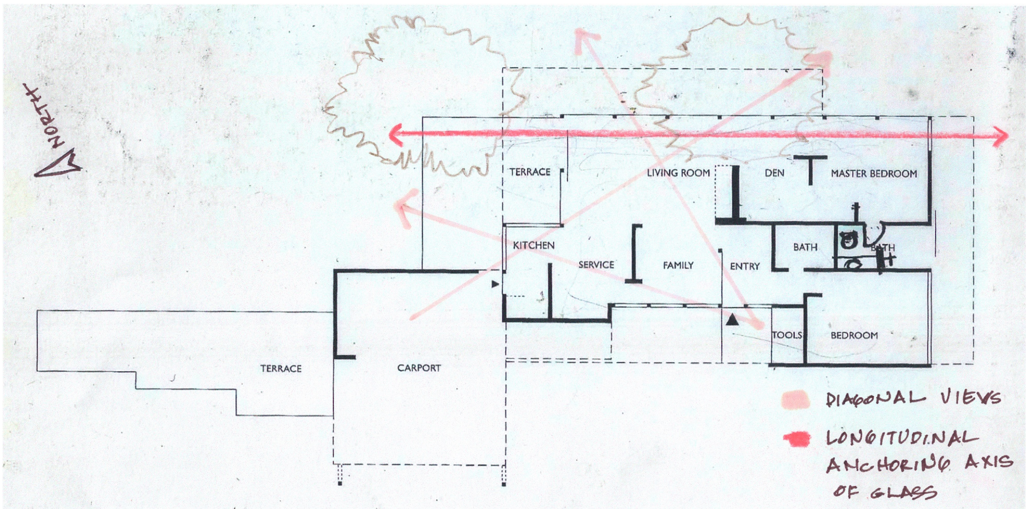


Fig. 3.29 - Richard Neutra - Taylor House. floor plan / longitudinal and diagonal axes

In this rectilinear box, specific trajectories for diagonal movement can be seen running in the path from the carport south to the living area, a private path, and then to the outdoors; or from the front door west to the living area and then to the outdoors. This design layout as many others by Richard Neutra are located in Southern California and benefit from the benevolent climate specific to the region.

The experiments made by Neutra in integrating interior and exterior space are theorized in his book „Nature Near".

Back in Europe, Horia Creanga was preoccupied as well with the dynamics of the open plan as can be seen in his exquisite villa Elisabeta Cantacuzino in Bucharest.

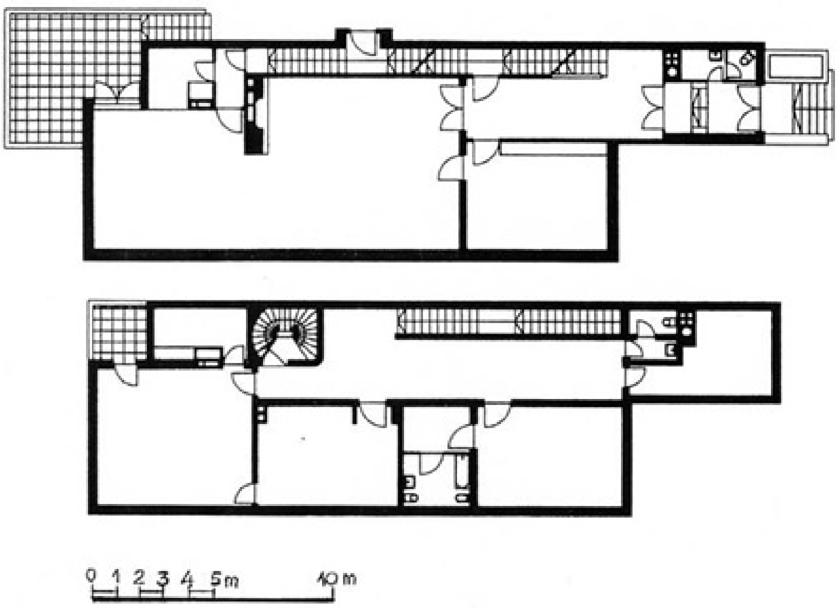


Fig. 3.30 Horia Creanga Vila Elisabeta Cantacuzino

Probably the most important moment in the development of the open plan came with the construction in 1951 of Farnsworth House by Mies van der Rohe.

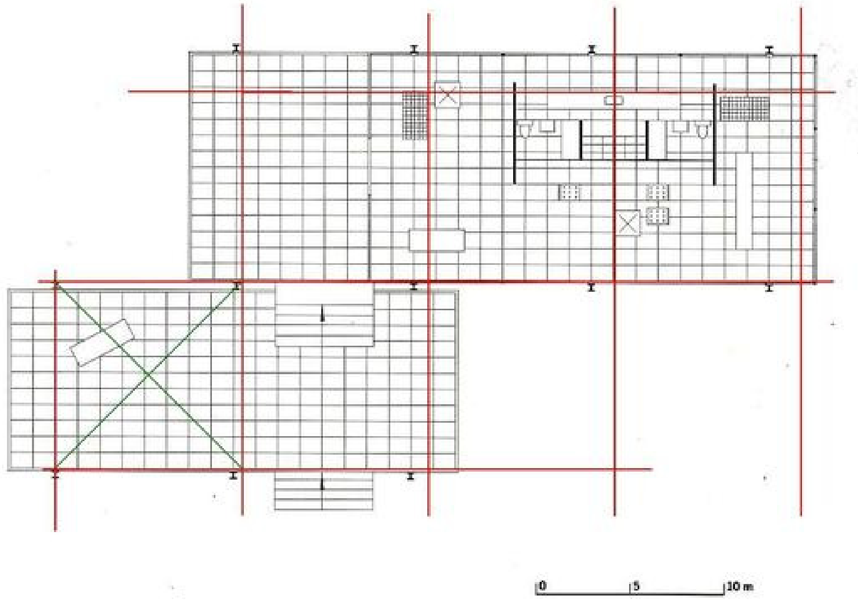


Fig. 3.31 - Mies van der Rohe – Farnsworth House, 1951

Conceived as a summer house, more of a pavilion than anything else, the design does not have to address the usual requirements of a permanent house and has therefore all the freedom in layout arrangement. Nevertheless, the project, superbly executed, continues to exert great attraction even today.

The free plan of Mies is very different. It seems to exist in a powerful magnetic field, the magnetism keeping the walls suspended in a tense configuration that prevents their ever touching. Furniture, too, is caught in the field, pulled away both from the solid partitions that modulate the space and from the glass line that forms a climatic but not a visual boundary. Beyond that glass line, wall, roof and floor planes may extend into surroundings that are imagined as uniform and limitless. The Miesian plan is open not just from area to area but, philosophically at least, to the universe. [66]

Mies van der Rohe's pupil and assistant, Phillip Johnson applied the same concept of a totally open layout to his vacation home. The Glass House is another example of pavilion architecture with far reaching influence for residential design ever since.

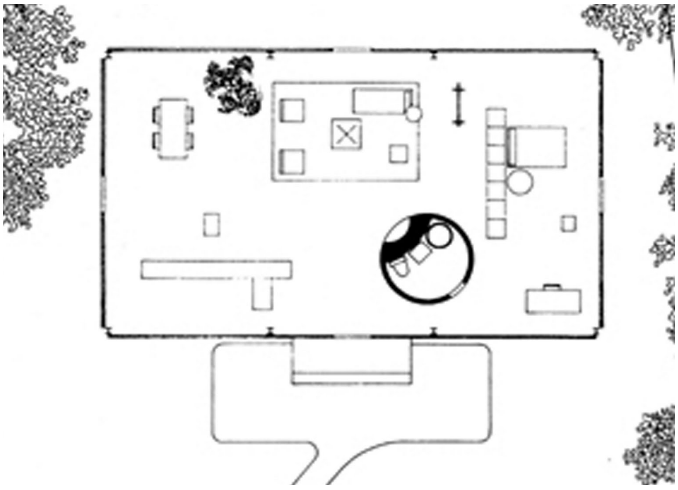


Fig. 3.32 - Phillip Johnson – Johnson House, New Canaan, Conn. 1949

The principles of the open plan, have proven to date their validity in luxurious homes only. Therefore, architects started to be preoccupied by the application of these principles to mainstream or affordable houses.

The McCormick House by the same Mies van der Rohe was exactly such an attempt.

Fig. 3.33 Mies van der Rohe – Mc Cormick House, Elmhurst, Il., USA, 1952

This house, however, was to be different. A simple, straightforward design would prevail, but it would be made "affordable" with the row houses in mind. Stock millwork was used for the moveable partitions, and single pane glass for the windows. The floors were to be concrete, covered with cork; the kitchen, a simple gallery plan, and there would be no air conditioning. The landscaping was planned by Alfred Caldwell, one of Mies' colleagues at Illinois Institute of Technology, and planted by his students.

The open space plan as conceived by Wright and developed by Neutra and Mies van der Rohe, for example, produces the most striking effects when applied to one or two storey high buildings. In such applications, the layout flexibility is gained through the flow of open space and generally through the large house dimensions.

In Europe, tighter lots led to more compact detached residential buildings, usually up to three storeys high. The search for open plan solutions and ultimately flexibility, can be seen in the iconic 1924 Rietveld-Schroeder House.

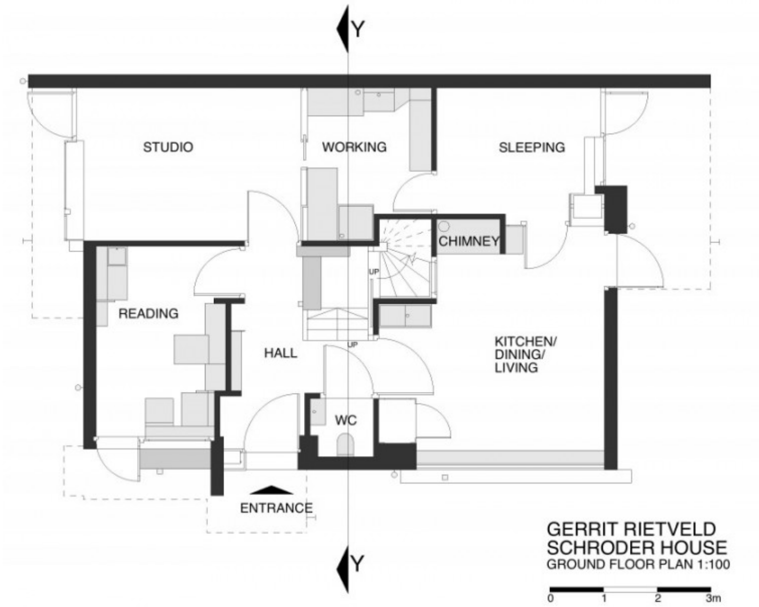
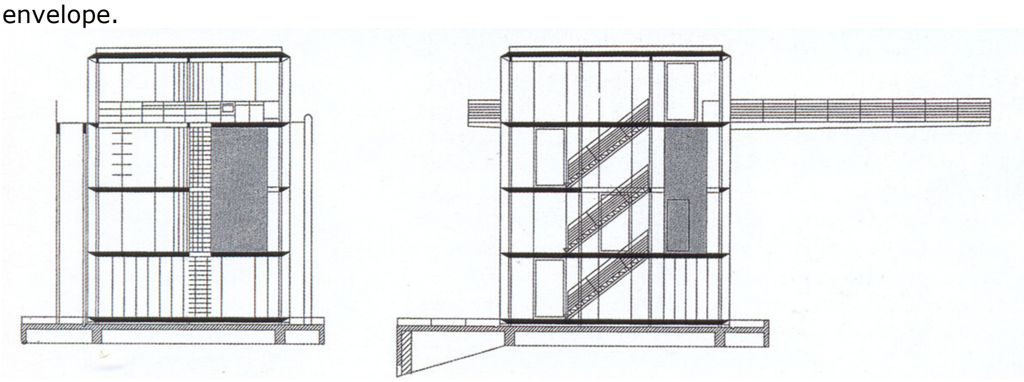


Fig. 3.34 Gerrit Rietveld House

The design direction pioneered by Gerrit Rietveld, brings us to the architectural solutions of today, between which the Sobeck House by Werner Sobeck, is one of the most notable. The design achieves flexibility and complete space openness through the use of slender steel structures and the use of glass as envelope.



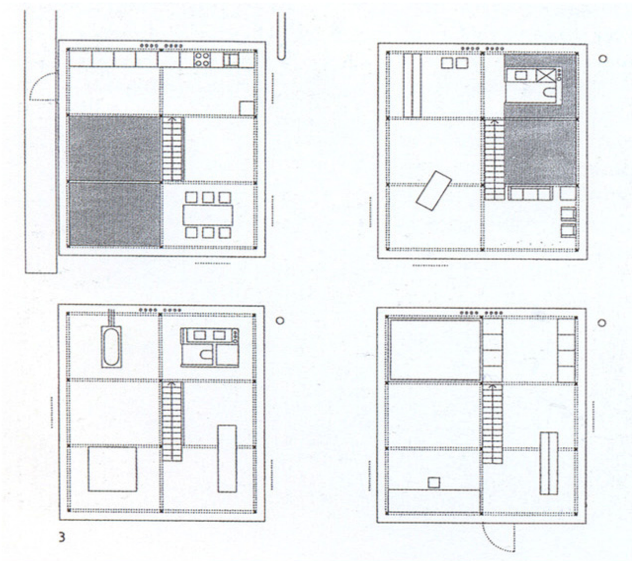


Fig. 3.35 Sobek house, 2001, Suttgart

3.5. Trends in Residential Design

The architectural object is a design product, would that be unique, short series or mass produced. The fulfillment of functional requirements is the key parameter to be observed. As a house has a life expectancy of up to 100 years, it is quite difficult to anticipate the kind of functional needs that will become necessary. The monitoring of living conditions and house trend design (Eurostat, US Census Bureau) is indicative mostly of the evolution of living habits, influenced by economics.

Starting in the last couple of years, some of the most important design trends in residential design are coming from the need to incorporate technology.

Other trends are born out of the necessity to adapt family life to a difficult or unpredictable economic times.

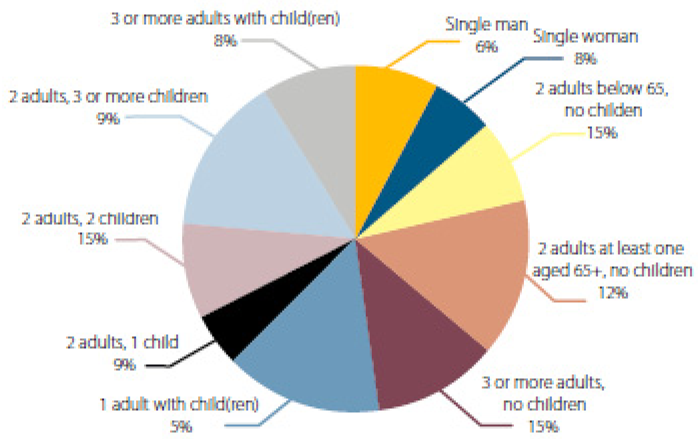
Given the fact that trends cannot be easily translated into finite space requirements, the common way of accommodating them is „layout flexibility”.

Style is an essential if elusive ingredient of the architectural product and is determined by a multitude of factors.

Incorporating technology in house design today complicates further the quest for style.

The way homes look and operate depends first and foremost on the people who live in them. The nuclear unit is suffering major modifications as a result of everything from economics to education, technology to health care.

The young generation has the tendency to live on its own to show economic independence, while seniors will be encouraged into living by themselves for longer with the help of new technology.



Notes: 1) Data for FI extracted from a special household sample. 2) No data for DK, IE and SE.
Source: EU Labour Force Survey, annual result.
Extraction date: 4.7.2008

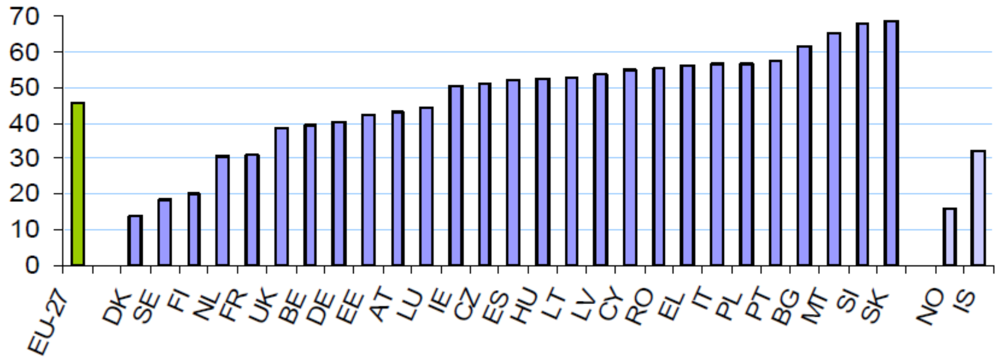
Fig. 3.36 Division of population living in private households, by household type

In the same time we are witnessing an opposite trend: multiple generations living under one roof. Growing numbers of retirees move in with their adult children, in order to help out with childcare and household activities.

At the same time, young adults stay to save money or return after graduation while they get their careers off the ground.

In 2008, approximately 46% of young adults aged 18-34 in the European Union still lived with at least one of their parents. The disparities across the EU have been examined so as to shed new light on the situation of young people in our societies. This topic is of particular relevance due to increasing focus of EU policies on young people and their participation in the labour market.

An interesting and relatively consistent pattern emerges. In northern countries, a low share of young adults live with their parent(s), while in southern countries, as well as in some new Member States, the share is three to four times higher.



Source: Eurostat calculations based on EU-SILC database

Fig. 3.37. Share of young adults aged 18-34 living with their parent(s) (%), 2008

Kitchen Design

Throughout history, the kitchen retained its position as the centre of the house. The place where the fire was burning and the family enjoyed the daily meals, was also the place for being together most of the time. This is true in all ages and cultures all over the world.

Fig. 3.38 P. House – Kitchen

The kitchen will likely remain the social centre of the house, where people meet to share meals or just gather around the table. Modern designs propose as a rule open kitchens, which bring the advantage of an increased living area. On the other hand, different cultures and different cuisines react differently to this trend.

Media Room

In the US the traditional family room is likely to become a computer-media centre, for playing, studying and socialising - something for everyone in a complex household. Media is the true "third place" where people of all ages retreat. This trend is spreading to Europe as well.

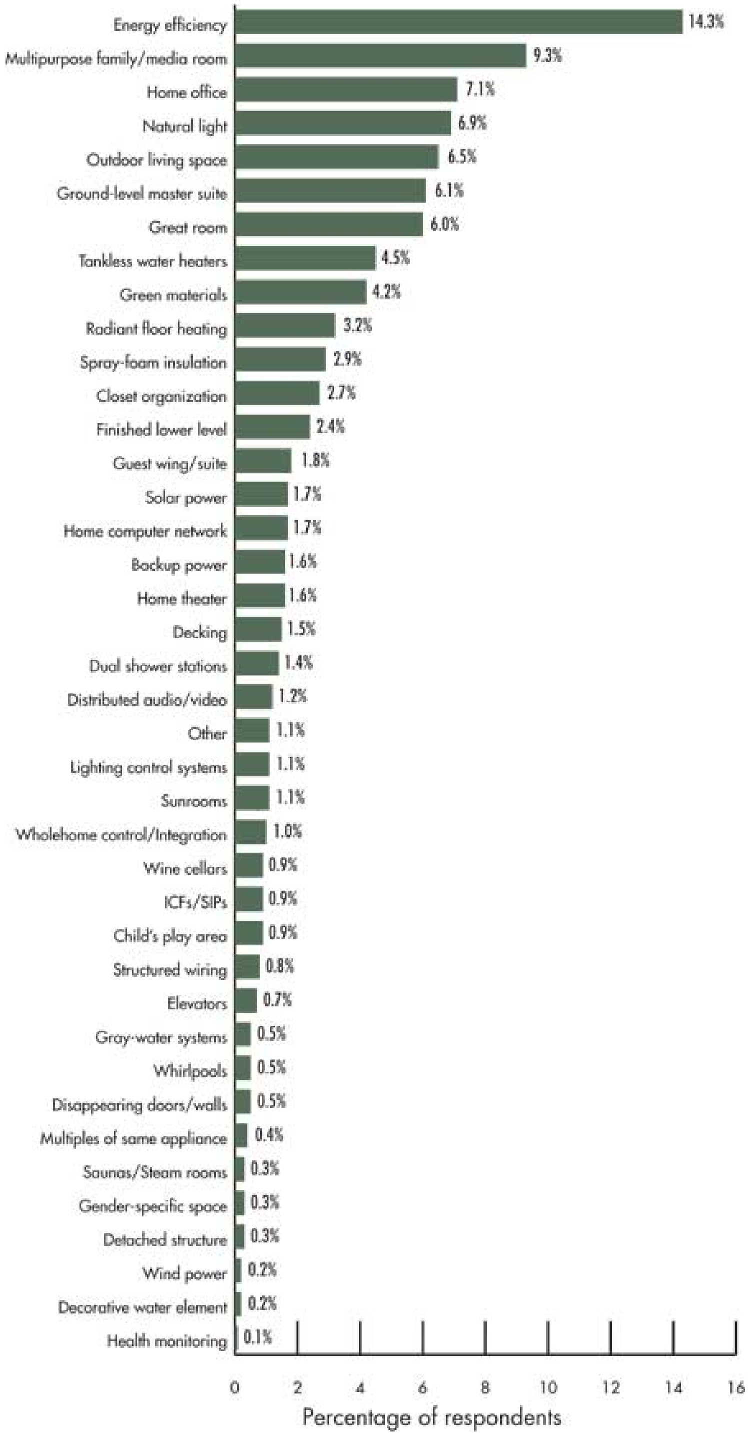


Fig. 3.39 Rooms or features preferred by customers

Working from Home

Employment patterns due to the economic crisis, have prompted the interest in the efficiencies of working at home via online networks linked to internal office servers. According to the human resources group WorldatWork, more than 100mil Americans, in 2010, worked from home at least one day per month.

The effect of telecommuting is eco-friendly. The Economist magazine recently reported that if the 33mil Americans who have jobs that could be done from home were to stay there instead of driving to work, US oil imports would drop by more than one quarter and carbon emissions would fall by 67mil metric tonnes a year.

Storage Space

Storage space is rarely properly dimensioned, usually to small for the functional requirements of the house. Living lifestyles are quite personal and the amount of clutter gathered differs from one family to another. The problem is that non-withstanding this fact, storage space has to be always sufficient. Being a dead space usually with no windows, positioning the storage on a layout is not as simple as it appears. One possible solution, developed lately is to conceive a container type unit, to be incorporated in the building or to be part of the garage. This way, beside the normal closets and dressings, a suitably proportioned and organized storage can be made available to the household.

Accessible Home Design

Home design has to address the growing needs of the elderly, meaning that it has to make buildings as accessible and easy to use as possible.

That means that one storey buildings are preferable. Two story buildings have to have at least one master bedroom on ground floor and make provision for an elevator or other mechanical means to access the upper floor. Spiral staircases, sunken living rooms, and high cabinets have all the contrary effect.

Architects often use the phrase "universal design" to describe these homes because they are comfortable for people of all ages and abilities.

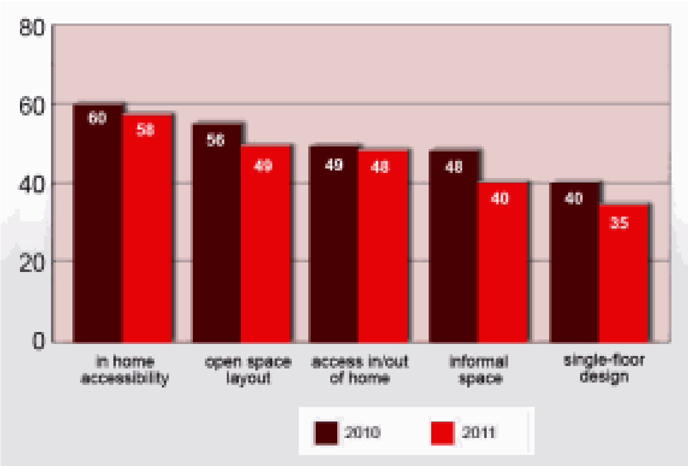


Fig. 3.40 Outdoor Rooms in Home Design, Aia Report

Garden design is the natural complement of house design and gardens in general are the chief reason people live in low-rise detached or semi-detached houses. Following the climatic conditions, gardens become the focus point of family activity for a sizeable part of the year. Blending architectural, garden, and interior designs is in fact the goal of residential design.

Therefore, whenever possible, a dialogue between the interior space and the outdoors, is encouraged. The yard and garden become a part of the floor plan when sliding glass doors lead to patios and decks. These outdoor "rooms" may even include kitchens with sophisticated sinks and grills.

Flexible Floor Plans in Home Design

Changing lifestyles calls for changing living spaces.

"An open space layout was another design priority seen as growing in popularity. With more pressure on space in the home, interest has grown in designing homes with more open space that gives the household more programmatic flexibility. Informal space is another lifestyle preference that remains popular"(*AIA Report).*

Allowing flexibility in living arrangements is the common way in which future functional requirements can be accommodated. This calls for large multi-purpose family areas, for sliding doors, pocket doors, and other types of movable partitions that allow flexibility. Larger rooms require bigger spans, which brings us back to the advantage of using steel in residential construction.

Earth-Friendly House Design

More and more house owners are concerned by the type of construction materials that make the building in which they live. This trend is in fact part of the increased sensitivity to the environment. Architects and engineers are taking a new look at ancient building techniques that used simple, bio-degradable materials. Some of them, considered until recently as primitive, are now accepted as eco-friendly. For example, far from primitive, today's "earth houses" are proving comfortable, economical, and rustically beautiful.

Adaptive Reuse in Home Design

New buildings aren't always entirely new. A desire to protect the environment and to preserve historic architecture is inspiring architects to repurpose, or re-use, older structures. Trend-setting homes of the future may be constructed from the shell of an outdated factory, an empty warehouse, or an abandoned church.

Healthy Home Design

Home designers are becoming increasingly aware of the ways our health is affected by synthetic materials and the chemical additives used in paints and composition wood products. The most innovative homes aren't necessarily the most unusual; they are the homes constructed without relying on plastics, laminates, and fume-producing glues.

Simplicity extends to home layouts

Reflecting the desire to keep homes affordable in the current weak housing market, home layouts have generally been simpler and floor plans more flexible. The one general exception to this trend is continued interest in accessibility into and around the home. As our population ages and households prefer to age in their current home, accessibility has become a growing concern. As a result, in-home accessibility was observed to be increasing in popularity by 58 percent of residential architect respondents, basically unchanged from a year ago. Accessibility into and out of the home was another design priority seen as growing in popularity by almost half of the respondents. A single-floor design is yet another consideration typically favoured by households with accessibility concerns. ***AIA Report***

Design vs. Market Expectations

The residential trends discussed above, have the power to influence architectural design, but nor to determine it all together.

Both design and building processes are heavily influenced by market

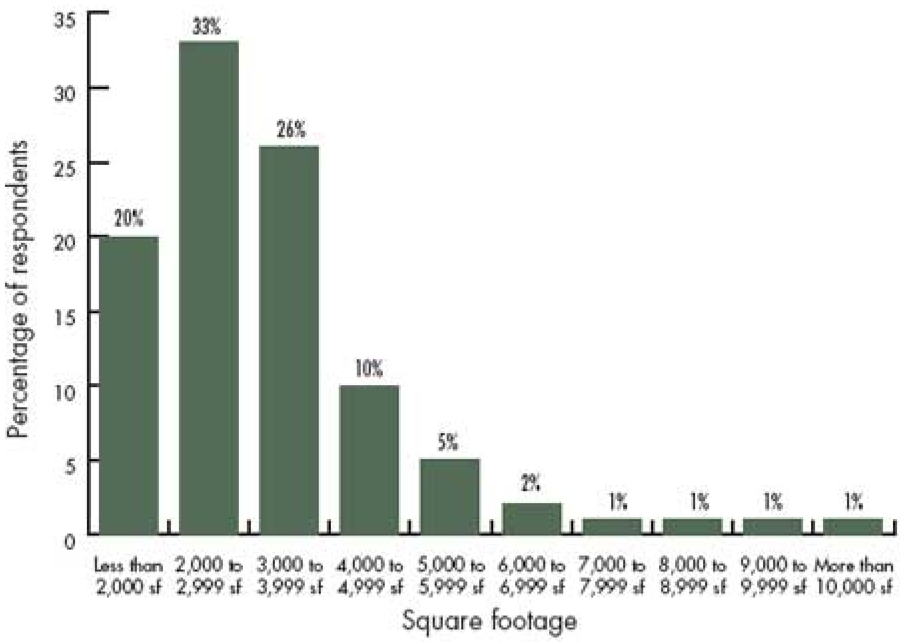


Fig. 3.41 Average square footage of custom homes designed or built in 2009

Conditions and similar design concepts can meet in the end the expectations of different types of clientele.

For example, the Ferne House and the typical American house, share a number of elements as a large central open space, etc., but differ fundamentally in architectural expression.

Fig. 3.42 Ferne House

Fig. 3.43 Typical American house

In the United States, residential market surveys point out to the following conclusions:

- the average new house has expanded in size from about 1500 square feet in the mid-70s to over 2000 (Friedman and Krawitz).
- people want more space - family homes have grown by 1/3 in size over the last twenty years.
- sizes of lots are decreasing, as sizes of homes are increasing. The median size for a new single family home in 2003 was about 2300 square feet (National Association of Home Builders). Family size has

decreased almost 25% over 30 years, while the size of new houses has increased about 50% (Heavens).

- Average lot sizes are decreasing.

New home profiles also anticipate more mixed-use communities, neo-traditional designs, neighbourhoods with smaller lots and narrower streets. New communities will most certainly offer more diverse architectural designs. 21st century neighbourhoods will be more diverse while maintaining high quality design standards. They will encompass live/work houses, commercial centres and close proximity to amenities and services. [34]

Larger homes on smaller lots will be one of many design challenges affecting new home construction in the years and decades to come. When height restrictions are not too strict, the solution is to go up and down. Homeowners could carve out more liveable space, which may have been previously delegated for storage, in their basements and attics. [34]

While size is on the decline, the desire for bigger homes is rising. Homebuyers want one-story homes, but builders have been responding to the demand for more living space by building more two-story homes. More stories allow expansion of interior space without increasing a home's footprint - the amount of land it uses. This has become more important as land becomes less available and more costly in many metro areas. [34]

To understand what will happen in the next 300 years to housing is a difficult task because we just don't know how technology, culture, and social relationships will evolve, thus changing how we use our homes, and how our homes change us. One thing is certain: land will be at a premium and expensive. The other certainty is that the population will continue to skyrocket and there just won't be the space for everyone to have large lot sizes for their homes. Another big unknown is energy sources and supplies. [34]

3.6. Low Energy Houses

Green building is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. Green building is also known as a sustainable or high performance building.

Fig. 3.44 Massai huts today

Environmentally responsible design is not as new as it might appear. From the Neolithic shelter to the Massai huts of today, mankind has produced countless viable building solutions, of the kind we call today *sustainable.* These so called primitive houses, coexist today with the most refined and technologically advanced residential buildings, as the one designed by noted engineer/architect Werner Sobek.

Fig. 3.45 Werner Sobek – House H16, 2006, Balinge

Given the striking differences between these two contemporary examples, one can easily see the difficulty to present an exhaustive picture of the trends in sustainable construction today.

Although new technologies are constantly being developed to complement current practices in creating greener structures, the common objective is that green buildings are designed to reduce the overall impact of the built environment on human health and the natural environment by:

- Efficiently using energy, water, and other resources
- Protecting occupant health and improving employee productivity
- Reducing waste, pollution and environmental degradation.

A similar concept is natural building, which is usually on a smaller scale and tends to focus on the use of natural materials that are available locally. Other related topics include sustainable design and green architecture.

Aspects of Built Environment:	Consumption:	Environmental Effects:	Ultimate Effects:
• Siting • Design • Construction • Operation • Maintenance • Renovation • Deconstruction	• Energy • Water • Materials • Natural Resources	• Waste • Air pollution • Water pollution • Indoor pollution • Heat islands • Stormwater runoff • Noise	• Harm to Human Health • Environment Degradation • Loss of Resources

Fig. 3.46 - Impacts of the built environment

For example, green buildings may incorporate sustainable materials in their construction (e.g., reused, recycled-content, or made from renewable resources); create healthy indoor environments with minimal pollutants (e.g., reduced product emissions); and/or feature landscaping that reduces water usage (e.g., by using native plants that survive without extra watering).

As can be seen the definition has a great level of generality.

The definition of low-energy building can be divided into two specific approaches: the concept of 50% and the concept of 0% (Zero-Energy or Passive House). The percentage numbers indicate the amount of energy these buildings use in comparison with the standard building constructed in accordance with current building regulations. A building constructed using the 50% concept consumes only one half of the heating energy of a standard building. It is typically a traditional building constructed by using standard solutions. The low energy consumption is based on an increased level of thermal insulation, high performance windows, airtight structural details and a ventilation heat recovery system.[4]

In the IEA Solar Heating and Cooling program, low energy houses were built and evaluated. The buildings were located in the following countries: USA-Arizona, USA-Grand Canyon (California), Belgium, Canada (Brampton and Waterloo), Denmark, Finland, Germany (Berlin and Rottweil), Italy, Japan, the Netherlands, Norway, Sweden and Switzerland.

The lessons learned from the project were the following:

> It is possible to design low-energy buildings that have high thermal comfort, good indoor air quality, and low environmental impact. The average total projected energy consumption of the evaluated buildings shows a reduction of 60% of the typical consumption in residential buildings.

> The total energy consumption does not differ very much from country to country. This is partly because the consumption for water heating, lights and appliances is relatively independent of climate, while the building codes are adopted to the prevailing climate in each country. The insulation levels are generally low in countries with mild climates and high in countries with cold climates. The energy consumption per square meter, therefore, does not differ as much as one would expect when looking at the climate differences.

> To make a proper evaluation it is necessary to consider the total energy use, and not to focus on space and/or water heating alone. It is also important to consider both heating and cooling, as several countries found that focusing on one

season only could lead to problems during the other season. Also, reducing cooling loads was often a greater challenge than reducing heating loads.

> Buildings function as a system, where the different technologies used are integral parts of the whole. The order in which the technologies are introduced into the design appears to be quite important. As a rule of thumb the best economics are achieved if different energy efficiency measures are considered in the following order:, energy-conservation technologies are considered first, passive solar second and active solar third. In most cases all of these technologies are used, often in combined systems. It is therefore wiser to develop whole building concepts rather than to develop specific technologies.

> Passive solar gains can make a major contribution to space heating in all climates and do not lead to overheating if proper solar protection is used. Heat recovery from exhaust air in the ventilation system is common in low energy buildings.

> Designing new, innovative building concepts requires a multi-disciplinary design team. The energy aspects should be considered at the early design stage, and the architects and engineers should work together from the start. The concept of Integrated Design Process and Integrated Design Solution are important in this regard and are now rapidly developing (Harvey 2006). The question became recently a priority theme for the CIB, International Council for Research and Innovation in Building and Construction.

> Training of builders and on-site supervision is particularly important in low-energy buildings. In low-energy buildings, the energy consumption is more influenced by construction practices and by user behavior than in conventional buildings, For instance, air tightness and the avoidance of thermal bridges is much more important in a well insulated building than in a traditional building, and the tightness of the ductwork is more critical as these buildings have more equipment (IEA 1997). [4]

Zero-energy buildings are buildings that produce as much energy as they consume over a full year. This approach represents one of the most challenging solutions in terms of environmentally responsible construction, requiring state-of-the-art, energy-efficient technologies and renewable energy systems such as solar and wind power. ‘Zero energy’ means that the energy provided by on-site renewable energy sources is equal to the energy used by the building. This solution minimizes the building’s impact on the environment and does not reduce the indoor comfort of the users. [4]

Zero-energy buildings are increasingly important in developed countries. They are seen as a potential solution to mitigating global warming and other environmental problems. It is also an alternative to economic vulnerabilities, such as the dependence on fuel imports of fossil fuels. [4]

A building that is approaching net energy consumption of zero may be termed a near-zero energy building or an ultra-low-energy building. Buildings that produce a surplus of energy are known as energy-plus buildings.

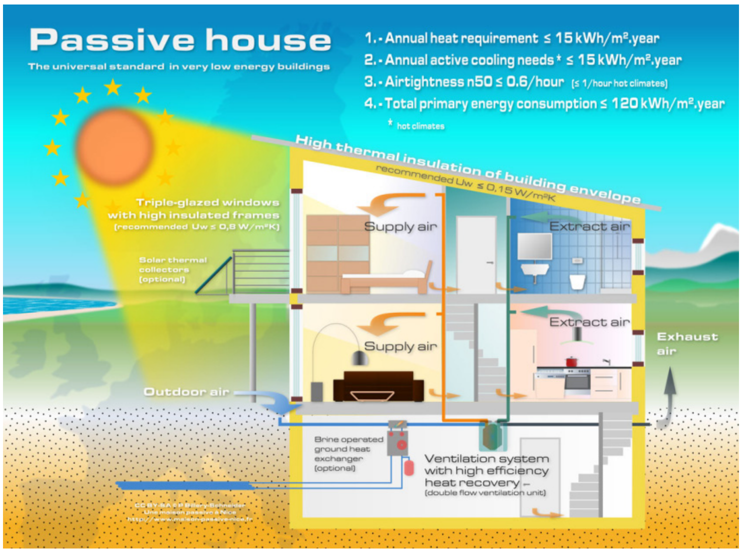


Fig. 3.47 - Passive House standards

The term "Passive House" is used for an internationally established building standard with very low energy consumption, which has been proven in practice. The Passive House standard is comfortable, sustainable and economically attractive. Originally developed in Germany for houses and low-rise multi-unit residential buildings, the standard has been applied to houses in a range of other countries and to commercial buildings as well. The concept was developed by Dr Wolfgang Feist and Prof. Bo Adamson in the late 80's and implemented in research in the 1990's.[17]

The most interesting aspect of the criteria of the Passivhaus standard may be that it has relatively few mandatory requirements, thereby providing design flexibility, and that it focuses exclusively on energy consumption.

Independently of the climate and functionality, the Passive House Concept is defined as follows, [Feist 2007]: A Passive House is a building in which thermal comfort [EN ISO 7730] can be guaranteed by post-heating or postcooling the fresh-air mass flow required for a good indoor air quality. [18]

This is the case where the heating load can be limited to 10 W per m² living area. In Central Europe, this means a space heat demand of 15 kWh/(m²a) at the most – this corresponds to a saving of 75% in comparison with the current standard and a saving of at least 90% in relation to existing buildings. A further reduction in the heating energy demand involves high investment costs which cannot be re-financed by the energy savings. However, it is already so low that it would be possible to meet the remaining heating requirement using a light bulb - the heating energy demand is about the same as the heat emitted by persons and devices which are internal heat sources. In the Passive House, a requirement for the total primary energy demand including all electrical applications is made. The limit for the Passive House standard is 120 kWh/(m²a) of the total primary energy. [18]

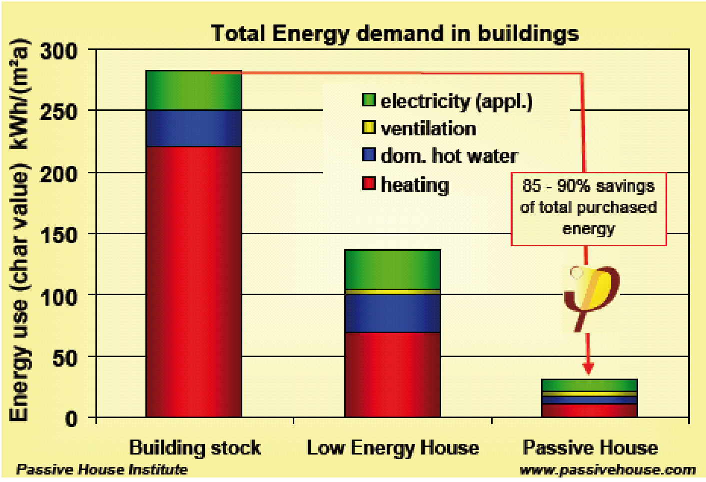


Fig. 3.48 – Energy demand in building

Even some of these requirements may not be actually be mandatory: in a 2008 interview in Energy Design Update Feist himself stated that the heating demand number could be anything. In this interview Feist also stated "As long as you build a house in a way that you can use the ventilation system … to provide heating and cooling it can be considered a Passivhaus." [17]

The typical Passive House approach is focused almost exclusively on the reduction of space heating loads, leaving the lighting, hot water, cooling, appliance and misc. electrical loads to fall under the "total primary" requirement. However, it is widely acknowledged that very efficient appliances and lighting must be used to meet the primary/source energy targets in most cases. [17]

Compact form and good insulation :	U-factor ≤0.15W/(m²K)
Orientation and shade considerations :	Passive use of solar energy
Energy-efficient window glazing and frames :	U-factor ≤0.80W/(m²K) (glazing and frames, combined) solar heat-gain coefficients around 50%
Building envelope air-tightness :	Air leakage ≤0.61/hour
Passive preheating or fresh air :	Fresh air supply trough underground ducts that exchange heat with the soil. This preheats fresh air to a temperature above 5°C (41°F), even on cold winter days
Highly efficient heat recovery from exhaust air :	Heat recovery rate over 80%
Hot water supply using regenrative energy sources :	Solar collectors or heat pumps
Energy-saving household appliences :	Low energy refrigerators, stoves, freezers, lamps, washers, dryers, etc. are indispensable in a passive hou

Source: Passive House Institute 2006.

Fig. 3.49 - Characteristics of passive houses. [4]

Almost all Passivhauses rely on:

- very heavy insulation, R-40 to R-60 walls, R-50to R-90 roofs, and often R-30 to 50 sub-slab insulation, triple-glazed low-e windows, and exceptional avoidance of thermal bridges (except for wood framing)

- ultra-airtight construction (<0.6 ACH@50) which, together with the R-value requirements, usually result in designers needing to choose simpler shapes

- passive solar gain for a portion of the heating by orienting the house to the south and using a window SHGC of around 0.5 (or higher if possible),
- heat recovery, in the past with earth tubes and more recently with dual core HRVs to reach high 80% to low 90s efficiency, but essentially always with supply air to each space with return air pathways, and
- heating of the ventilation air to provide space heating, although many homes use radiant floors, walls, ceilings, and radiators. [17]

The diversity of solutions is, however, large, and could be considered a strength of the program. There are Passivhauses that use gas boilers to provide heating, and those that include solar hot water and/or PV, and wood stoves.

Window specifications are also demanding. A common specification is for U=0.15 (0.8 W/m2 K) or less for windows. To approach these targets windows certainly need to have non-conductive frames (vinyl, wood or fiberglass) and triple-glazing, low-e coatings and gas. [17]

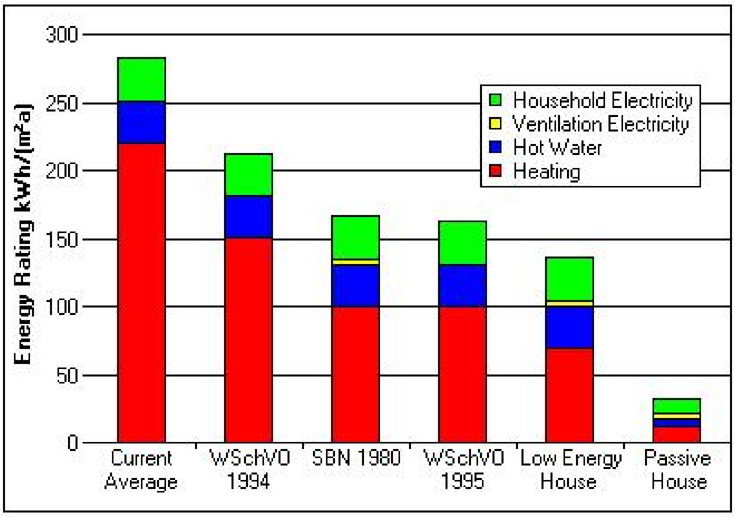


Fig. 3.50 - Comparison of Energy Ratings of Homes [18]
WSchVO = German Heat Protection Regulation
SBN = Swedish Construction Standard

The fulfillment of one or more of the stated goals, coupled with the building techniques and materials available today, have the potential to produce a great variety of "green buildings" types. Therefore, it is very difficult to identify all the combinations possible and , as a result, a review cannot be by any means complete.

For the purpose of this thesis, in order to be able to discuss the main green building types (i.e. low rise residential) we will consider only the construction methods and construction materials parameters.

Low-Energy Houses

In what follows, we'll try to exemplify the wide variety of low-rise residential buildings, which are using sustainable building techniques. The examples are grouped into two main categories, loadbearing wall structure and framed structures.

Houses Using Loadbearing Wall Structures

Adobe is a natural building material made from sand, clay, water, and some kind of fibrous or organic material (sticks, straw, and/or manure), which the builders shape into bricks using frames and dry in the sun. Adobe buildings are similar to cob and mudbrick buildings. Adobe structures are extremely durable, and account for some of the oldest existing buildings in the world. In hot climates, compared with wooden buildings, adobe buildings offer significant advantages due to their greater thermal mass, but they are known to be particularly susceptible to earthquake damage. [19]

An adobe wall can serve as a significant heat reservoir due to the thermal properties inherent in the massive walls typical in adobe construction. In tropical and other climates typified by hot days and cool nights, the high thermal mass of adobe levels out the heat transfer through the wall to the living space. The massive walls require a large and relatively long input of heat from the sun (radiation) and from the surrounding air (convection) before they warm through to the interior and begin to transfer heat to the living space. After the sun sets and the temperature drops, the warm wall will then continue to transfer heat to the interior for several hours due to the time lag effect. Thus, a well-planned adobe wall of the appropriate thickness is very effective at controlling inside temperature through the wide daily fluctuations typical of desert climates, a factor which has contributed to its longevity as a building material.

Fig. 3.51 - Romanian adobe house during construction

Superadobe is a form of earthbag construction that was developed by Iranian architect Nader Khalili. The technique uses layered long fabric tubes or bags filled with adobe to form a compression structure. On top of each layer of tamped, filled tubes, a tensile loop of barbed wire is placed to help stabilize the location of each consecutive layer: it plays a crucial role in the tensile strength of the dome - it is the 'mortar'. [20]

The resulting beehive shaped structures employs arches, domes, and vaults to create single and double-curved shells that are strong and aesthetically pleasing. It has received growing interest for the past two decades in the Natural building and Sustainability movements.

Fig 3.52 - Superadobe homes pioneered by the California Earth Art Architecture Institute.

Rammed earth is a technique for building walls using the raw materials of earth, chalk, lime and gravel. It is an ancient building method that has seen a revival in recent years as people seek more sustainable building materials and natural building methods. Rammed-earth walls are simple to construct, incombustible, thermally massive, strong, and durable. They can be labour-intensive to construct without machinery (powered tampers), however, and they are susceptible to water damage if inadequately protected or maintained. Rammed-earth buildings are found on every continent except Antarctica, in a range of environments that includes the temperate and wet regions of northern Europe, semiarid deserts, mountain areas and the tropics. The availability of useful soil and a building design appropriate for local climatic conditions are the factors that favour its use. [21]

Building a rammed-earth wall involves compressing a damp mixture of earth that has suitable proportions of sand, gravel and clay (sometimes with an added stabilizer) into an externally supported frame or mould, creating either a solid wall of earth or individual blocks. Historically, such additives as lime or animal blood were used to stabilize the material, whilst modern construction uses lime, cement or asphalt emulsions.

The compressive strength of rammed earth can be up to 4.3 MPa (620 psi). This is less than that of concrete, but more than strong enough for use in domestic buildings. Indeed, properly built rammed earth can withstand loads for thousands of years, as many still-standing ancient structures around the world attest. Rammed earth using rebar, wood or bamboo reinforcement can prevent failure caused by earthquakes or heavy storms. Adding cement to clay-poor soil mixtures can also increase a structure's load-bearing capacity. The USDA has observed that rammed-earth structures last indefinitely and could be built for no more than two-thirds the cost of standard frame houses. [22]

Soil is a widely available, low-cost and sustainable resource, and utilizing it in construction has minimal environmental impact. This makes rammed-earth construction highly affordable and viable for low-income builders. Unskilled labour can do most of the necessary work, and today more than 30 percent of the world's population uses earth as a building material.

One of the significant benefits of rammed earth is its high thermal mass; like brick or concrete construction, it can absorb heat during the day and release it at night. This moderates daily temperature variations and reduces the need for air conditioning and heating. It often requires thermal insulation in colder climates, again like brick and concrete, and must be protected from heavy rain and insulated with vapour barriers. Rammed earth can contribute to the overall energy-efficiency of buildings. The density, thickness and thermal conductivity of rammed earth make it a particularly suitable material for passive solar heating. Warmth takes almost 12 hours to work its way through a wall 35 cm (14 in) thick. [22]

Fig. 3.53 - Drew Owens - Rammed earth house - Placitas, New Mexico, 2008

Compressed Earth Block often referred to simply as CEB, is a type of manufactured construction material formed in a mechanical press that forms an appropriate mix of dirt, non-expansive clay, and an aggregate into a compressed block. Creating CEBs differs from rammed earth in that the latter uses a larger formwork into which earth is poured and tamped down, creating larger forms such as a whole wall or more at one time. CEB blocks are installed onto the wall by hand and a slurry made of a soupy version of the same dirt/clay mix, sans aggregate, is spread or brushed very thinly between the blocks for bonding. There is no use of mortar in the traditional sense. (This is not necessarily true for vertical presses, see link at bottom of page)

The advance of CEB into the construction industry has been driven by manufacturers of the mechanical presses, a small group of eco-friendly contractors and by cultural acceptance of the medium in areas where it is seen as superior to adobe. The advantages of CEB are in the wait time for material, the elimination of shipping cost, the low moisture content, and the uniformity of the block thereby minimizing, if not eliminating the use of mortar and decreasing both the labor and materials costs.

Cob or cobb is a building material consisting of clay, sand, straw, water, and earth, similar to adobe. Cob is fireproof, resistant to seismic activity, and inexpensive. It can be used to create artistic, sculptural forms and can be found in a variety of climates across the globe. Traditionally, cob was made by mixing the clay-based subsoil with straw and water using oxen to trample it. The earthen mixture was then ladled onto a stone foundation in courses and trodden onto the wall by workers in a process known as *cobbing*. The construction would progress according to the time required for the prior course to dry. After drying, the walls would be trimmed and the next course built, with lintels for later openings such as doors and windows being placed as the wall takes shape. [23]

The walls of a cob house were generally about 24 inches thick, and windows were correspondingly deep-set, giving the homes a characteristic internal appearance. The thick walls provided excellent thermal mass which was easy to keep warm in winter and cool in summer. Walls with a high thermal mass value act as a thermal buffer inside the home. The material has a long life span even in rainy climates, provided a tall foundation and large roof overhang are present

The technique has been revived in recent years by the natural building and sustainability movements. In the Pacific Northwest of the US there has been a resurgence of cob building both as an alternative building practice and one desired for its form, function and cost effectiveness.

Fig. 3.54 - An example of a modern, Pacific Northwest-style cob home

Sod has played an important role in the history of home building in America. When people began to push West, they needed to work with local materials to build homes in their new areas. Sod was one of the most common of these materials to be used in the Midwest. Sod homes were constructed all throughout the 19thcentury as the frontier boundaries were pushed further West. And some of those sod homes are still standing today, a testament to the longevity of alternatively built homes. The difference between sod and other earth-based materials is that sod is earth that includes grass. In contrast, most other earth-based materials are used in areas in which grass is not as common and the earth itself is the basic building material. In places that are wet and in which grass grows in abundance, people build with sod. The earth in these areas may be softer and less easy to build with, but the roots of the grass hold the earth together and create a terrific building material. In comparison with the other earth-based building materials, sod is one of the least expensive options. This is especially true for people living in areas where they can harvest the sod locally. [24]

Fig 3.55 – Sod houses

Straw-bale construction is a building method that uses bales of straw (commonly wheat, rice, rye and oats straw) as structural elements, building insulation, or both. This construction method is commonly used in natural building or "green" construction projects.

Straw bale building typically consists of stacking rows of bales (often in running-bond) on a raised footing or foundation, with a moisture barrier or capillary break between the bales and their supporting platform. Bale walls can be tied together with pins of bamboo, rebar, or wood (internal to the bales or on their faces), or with surface wire meshes, and then stuccoed or plastered, either with a cement-based mix, lime-based formulation, or earth/clay render. The bales may actually provide the structural support for the building ("load-bearing" or "Nebraska-style" technique), as was the case in the original examples from the late 19th century. [26]

Fig. 3.56 - Sarah Wigglesworth & Jeremy Till – The Straw Bale House

Alternatively, bale buildings can have a structural frame of other materials, usually lumber or timber-frame, with bales simply serving as insulation and plaster substrate, ("infill" or "non-loadbearing" technique), which is most often required in northern regions and/or in wet climates. In northern regions, the potential snow-loading can exceed the strength of the bale walls. In wet climates, the imperative for applying a vapor-permeable finish precludes the use of cement-based stucco commonly used on load-bearing bale walls. Additionally, the inclusion of a skeletal framework of wood or metal allows the erection of a roof prior to raising the bales, which can protect the bale wall during construction, when it is the most vulnerable to water damage in all but the most dependably arid climates. A combination of framing and load-bearing techniques may also be employed, referred to as "hybrid" straw bale construction. [26]

Advantages of straw-bale construction over conventional building systems include the renewable nature of straw, cost, easy availability, and high insulation value. Disadvantages include susceptibility to rot and high space requirements for the straw itself.

Masonry is one of the oldest construction methods in the world because it has great load-bearing strength and it’s inherently durable. Most masonry is made from inert, weather- and fire-resistant materials. With proper care, the service life of a masonry building can be extended to several centuries.

According to the BRE publication *Sustainable Masonry Construction* by Mark Key, the embodied energy contained in around 10 old bricks is equivalent to that contained in a gallon of petrol. This doesn’t sound great from an environmental perspective but it’s worth remembering the potential locked up in a brick. A brick can last a very long time (think Hampton Court Palace and other Tudor structures), provides excellent thermal mass and is often attractive so can contribute to a sense of place. [25]

Moreover, when brick from demolished masonry buildings meets currents standards, it goes right back into more buildings, not landfills. No extra energy is taken in this recycling process, unlike glass, plastic, paper and other materials that have to be broken down and reconstituted to be re-used. If used brick doesn’t meet standards for re-use, it can be crushed, broken, or used for road-fill or landscaping.

The use of heavyweight construction materials with high thermal mass (concrete slab on ground and insulated brick cavity walls) can reduce total heating and cooling energy requirements by up to 25% compared to a home built of lightweight construction materials with a low thermal mass.

The latest options for greater sustainability and savings through brick include:

- Buying local: like farm to table, brick is made from local resources that reduce the use of fossil fuels;
- Brick exteriors for energy efficiency/savings on fuel bills: brick's exceptional thermal mass allows it to absorb and store heat to release at a later time, reducing the load on the home's heating and cooling system
- Interior brick walls as part of passive solar design/energy harvesting
- Using salvaged brick: a growing trend among builders, brick is one of the few materials that building codes actually allow to be reused in a building application and keeps materials out of landfill
- Brick landscaping that integrates into natural surroundings: brick patios, archways, garden walls, fountains, pathways, planters and driveways add

durable value with low maintenance; light colored pavers can reflect a significant amount of solar energy, reducing the heat island effect

- Brick paver for efficient water management/drainage: permeable brick walkways and pathways help reduce storm water runoff, puddles and filter pollutants/eliminate contaminates
- Low-emitting materials: using brick throughout the house provides wall and floor surfaces that do not require paint or coatings
- No maintenance: no power washing, no repainting, brick's beauty endures without added materials or labor [25]

In contemporary buildings, masonry is used in combination with reinforced concrete structural elements, in order to ensure the required structural design criteria. Therefore, in masonry structures, the reinforced concrete component has to be taken into account when sustainability performances are rated.

Insulated Concrete Forms Homes (ICFs) look the same as conventional new homes both inside and out. ICFs are forms or moulds that have built-in insulation for accepting reinforced concrete. ICF structures are built using conventional house plans and refined with conventional exterior finishes. According to the ICF Builders Network, reinforced concrete homes have the following advantages over wood structures:

- constant temperatures that don't give access to drafts or cold spots
- non toxic: no CFCs, HCFCs, or formaldehyde
- a 2-hour fire rating
- termite and pest resistant
- can withstand severe storm hits
- no rotting or moulding
- can support concrete floor and roof systems
- help eliminate outside noise
- require an estimated 44% less energy to heat and 32% less energy to cool than comparable frame houses

Fig. 3.57 - Insulated Concrete Forms Home

Framed houses

Reinforced concrete is one of the most widely used modern building materials. Concrete is an "artificial stone" obtained by mixing cement, sand, and aggregates with water. Fresh concrete can be molded into almost any shape, giving it an inherent advantage over other materials.

Along with masonry, reinforced concrete seems to be the material of choice for housing construction being extensively practiced in many parts of the world, especially in developing countries, due mainly to its relatively low initial cost compared to other materials such as steel.

The use of concrete can offer some sustainability benefits in the life cycle of buildings and structures. Its thermal mass is highly efficient in reducing the energy needed to heat and cool buildings, and it also allows a high level of air tightness. It is highly durable and so needs minimal maintenance and can thus reduce whole life costs. Furthermore, the long life of the material means that concrete structures are appropriate for change of use. [27]

Concrete's mass and damping qualities allow good acoustic performance and minimise movement, reducing floor vibration. This is particularly advantageous for high density accommodation. It is non-combustible and has a slow rate of heat transfer which makes it a highly effective barrier to the spread of fire. The nature of the material also ensures that it is resilient to flood damage.

Structural engineers are reluctant to use recycled aggregate from crushed concrete in structural concrete. In northern climates recycled concrete from pavement may be contaminated with road salts, which is undesirable because it may promote corrosion in steel reinforced concrete. However, recycled concrete is frequently used as clean fill around foundations or base for pavements. [27]

The main disadvantage of the reinforced concrete stems from the high embodied energy of the materials used. The cement industry is estimated to contribute to 5% of all anthropogenic CO_2 emissions. On average, 50% of these emissions stem from chemical changes of the raw material, 40% from fuel combustion and 5% from both electric power and transport (Kruse 2004).[4]

Timber framing is the method of creating framed structures of heavy timber jointed together with various joints, but most commonly originally with lap jointing, and then later pegged mortise and tenon joints. Diagonal bracing is used to prevent "racking", or movement of structural vertical beams or posts

Timber frame homes are increasing in popularity. The increased focus on build sustainability, carbon footprints and the economics of insulation has brought timber frame construction to the fore. Timber is the ultimate *"green"* construction material. During a tree's lifetime, it removes tonnes of carbon dioxide from the atmosphere. This method of construction therefore helps control CO_2 emissions.

Timber is a natural insulator and timber frame walls have additional insulation included as standard. So timber frame is thermally very efficient.

Wood is a renewable resource, but it is not in endless supply and needs considerable time to grow. The use of wood for structural framing is therefore common in countries with important wood resources, as Canada, US, the Scandinavian Countries.

Recycling timber is less common as it is both inefficient and labour-intensive. The adhesives used when building with timber further complicate the recycling process.

Wood members have to be kiln dried and chemically treated, and the chemicals used to treat timber require careful disposal and limit the ability to recycle or reuse these materials.

Timber frames feature less embodied energy which means they use less energy in production from raw materials. However, when you consider that less steel is required to construct a new home and because steel doesn't take up landfill, the margin of embodied energy is very narrow.

Romania has significant wood resources, therefore the use of wood for structural framing starts to be used for low rise residential applications.

Low rise residential wood construction is not very common in Romania even though some progress has been made in the last 15 years. Wood is used mainly for roof framing (square wood).

For the time being, wood construction in Romania, even though regulated by legislation (seismic design legislation for wood NP 005-2003), is not subject to the same degree of safety verification protocols as steel construction is.

A bamboo timber framed house can be assembled quickly. The use of the Bamboo structure allows for a shallower foundation than the traditional masonry or concrete homes which saves time.

The bamboo home exhibits good resistance to earthquakes: The light weight yet extremely tough bamboo structures absorb seismic forces. The box-shaped structure components interact well to absorb tremors and vibrations, maintaining structural integrity even in strong earthquakes.

Fig. 3.58 - Eco Hale Hybrid Wood-Bamboo House

Bamboo has good insulation properties: Bamboo has a natural organic polymer body, its structure of fibre bundles and thin-walled cells means it has low heat conduction and is an excellent insulator. When compared to other homes, the bamboo structure greatly reduced energy consumption for heating and cooling.

The bamboo house is extremely cheap. Also, once the infrastructure for large scale production of bamboo lumber is in place, the cost of housing will be further reduced.

Steel Framed Houses

Steel as a construction material, plays an important role as a component for buildings and engineering structures, and it has a wide range of applications. On the other hand, steel is the most recycled material, and from the total production in the world, almost half is obtained from waste material.

The review of the steel construction sector's current position has demonstrated that:

• Steel construction is efficient, competitive and makes a significant contribution to the national economy.

• Buildings can be rapidly constructed using steel based components that are efficiently manufactured off-site and therefore are of high quality and with few defects.

• Steel framing and cladding systems, in association with other materials, encourage the design of buildings with low overall environmental impacts.

• Steel-based construction systems provide flexible spaces which can be easily modified and adapted.

The life of the building can be extended by accommodating changes in use, layout and size.

• At the end of the useful life of buildings, steel components can be dismantled relatively easily.

Reclaimed steel products can be reused or recycled without degradation of properties.

• Off-site manufacture promotes a less itinerant workforce. This tends to increase safety, promote stability in the workplace, encourage skills development and foster good local community relations.

Steel does not require insecticides or other chemicals to combat pests, mould or rot since steel is an inorganic material and does not absorb liquids. Therefore, a home constructed with Light Gauge Steel Framing does not promote the development of mould and other allergens. Nor does steel emit any volatile organic compounds that could cause hypersensitivity or allergies.

Light gauge steel framing represents a valuable solution from an environmental point of view because it is a dry construction system without organic materials. Dry construction significantly reduces the risk of moisture problems and sick building syndrome (Burstrand 2001); steel, gypsum and mineral wool are closed cycle materials, each of them can be recycled to 100%. In particular, the most of the steel members in a CFS construction are realized with recycled steel, which makes members that are durable, separable, dismountable and reusable. Moreover, the easy assembling and disassembling of cold formed steel structures allow constructions to be built up and disassembled with small amount of waste material. Light gauge steel framing means less energy consumption during production than equivalent housing with a framework of concrete poured on-site. Light gauge steel framing only uses about a fourth of the amount of raw materials used for equivalent homes in concrete and low dead weight of building components ensures a good working environment and leads to reduced transport needs. [28]

Therefore, the competitiveness of a CFS house's ecological balance is mainly based on the use of recyclable materials, light gauge components, dry-construction, easy assembling and disassembling, reduced amount of wasted materials, reuse of elements.

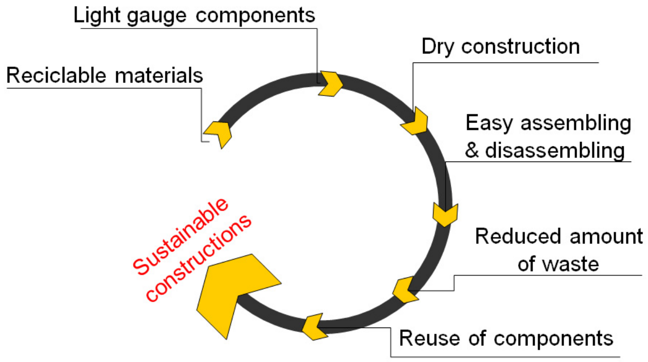


Fig.3.59 - Life cycle for cold formed steel construction (Iuorio, 2009)

The sustainability of a residential building is also strongly correlated to the internal comfort and energy saving. The trend today is to use gypsum board and vapor barrier on studs. Currently, some directions of the research focus on finding alternatives, i.e. new or traditional materials which allow for vapor migration to the wall cavity and could provide thermal inertia. [28]

Examples of eco-houses

The succinct presentation of sustainable applications in residential design, shows the great variety of materials and techniques available.

Before concluding, we would like to present three different approaches of sustainable design, taken from three continents and reflecting in their personal way, the same philosophy.

First, the summer home of noted British designer Sir Terence Conran, in Normandy, France, a typical "A" frame building which uses a timber structure.

The structure of the house is made of timber. Exterior cladding consists of red cedar shingles imported from Canada. These naturally weather over time to an attractive silvery colour. No applied finishes or treatments were used on the external joinery, which is made of recycled local timber. Instead, the wood was lightly charred to protect it from ultraviolet light and to increase its water resistance – a time-honoured method of timber protection that was much used in vernacular construction.

Fig. 3.60 - Eco House Sir Terence Conran

The tall, pointed structure is a modern version of a traditional agricultural building, built entirely out of wood, except for the minimal concrete piles that anchor it to the ground. It is not connected to the electrical grid and has many eco features, chief among which is its orientation. The glazed gable end of the house faces south. During the winter, low sunlight penetrates into the interior and warms it, while in the summer the sun is too high to cause overheating.

Natural stack ventilation is promoted by six trapdoors under the house and openings high up. Supplementary heating is provided by a wood-burning stove clad in masonry, similar to the traditional kachelofen that is common in northern Europe and parts of France, such as Alsace. Using the principle of the brick in a storage heater, these masonry stoves warm up slowly and release heat gradually. To operate most efficiently, it is necessary to place the stove centrally and leave the doors open so that heat can circulate – not a problem here, where there are minimal partitions.

Secondly, the EcoTerra^{TM} House, made by the Alouette Company, is one of the 12 projects in Canada that has been nominated by the Canadian Mortgage and Housing Corporation (CMHC) within the framework of the EQuilibrium initiative for the construction in 2007 of a new generation of energy efficient sustainable house. Its characterisitics are based on fundamental principles such as health and occupants comfort, energy efficiency, renewable energy production, resource conservation and reduction of environmental impacts.

Fig. 3.61 - Eco Terra / Canada/ Alouette House

The comparison of Conran's house with the Alouette house in Canada, shows how two similar timber structural systems can produce two solutions so far apart.

In truth, the comparison of a summer vacation home with a standard Canadian house is not possible. Nevertheless, the architectural expression, i.e. the preoccupation to integrate technology set this two examples far appart.

The early work of Lee Porter Butler, Double Envelope House, 1975 and the Barra system by Horatio Barra, are landmarks which inspired many designs of a kind.

The Armadillo Box Project by the Architectural School of Grenoble, is a fine example of double envelope residential building. The measurements made on the prototype built to date, demonstrate the performances of this house and clearly situates it in the low energy category.

Fig. 3.62 Architecture School of Grenoble - The Armadillo Box, 2010

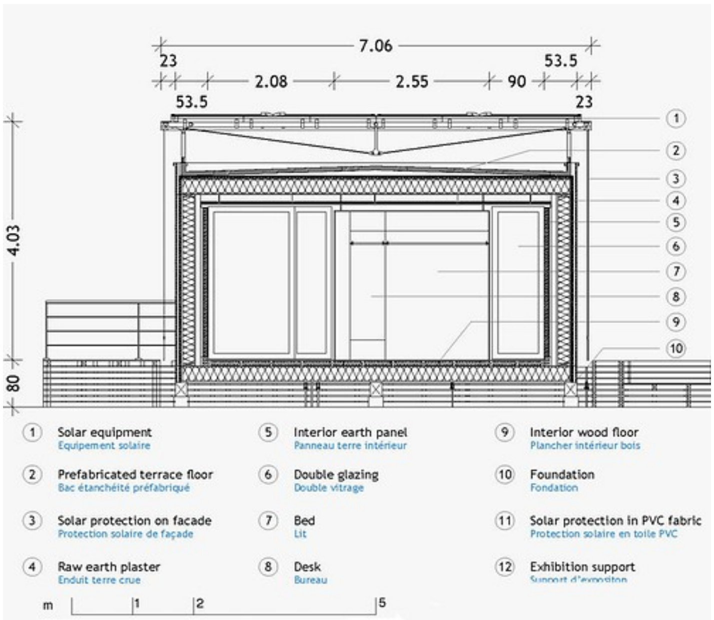


Fig. 3.63 Architectural School of Grenoble - The Armadillo Box, 2010 – cross-section

The Armadillo Box was inspired by its namesake, a sturdy desert creature whose unique outer shell and slow metabolism helps it keep cool in the desert heat. The team from France utilized the same concept to minimize energy use and excess heat by locating their core energy systems inside the house. Prefabricated modules utilizing common and inexpensive materials form the main structure, while an exterior shell covers the whole house, providing shade and generating power with a large photovoltaic system.

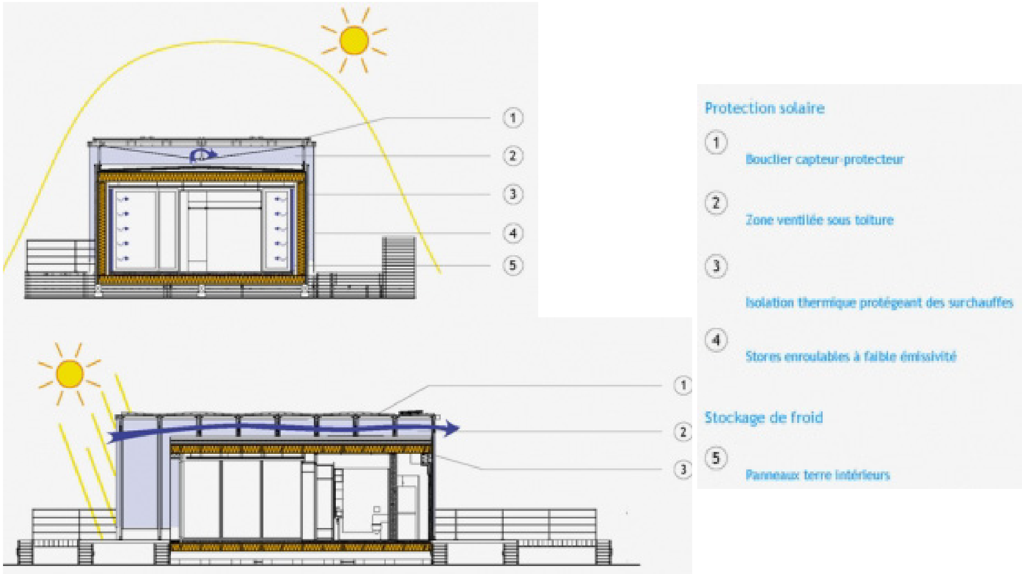


Fig. 3.64 Architectural School of Grenoble - The Armadillo Box, 2010 – solar protection

Designed for a couple, the interior of the home is efficiently laid out, flexible, and can easily expand with large doors that open onto a deck. Furniture was designed to be easily moved for different configurations like sleeping or entertaining, allowing the residents to make the best use of the home's efficient and simple interior. Floor-to-ceiling windows are shaded by a large overhang on the southern facade, allowing them to bring in natural sunlight while keeping out the hot sun. Rainwater can be collected, which supplies the water-efficient cooling mist system.

3.7. Conclusions to Chapter 3

The overview of residential layouts evolution analyzed in conjunction with the specific requirements of architectural design, shows that, for the average contemporary house, the fulfilment of functional requirements is determined essentially by the available resources and building technology and economics.

As stated in the introduction to this chapter, our objective was, as well, to situate steel farmed residential construction in the wider context of low energy building today. The wide array of contemporary building solutions, some of them coming from Neolithic times and other incorporating the latest technological advances, show that there is more than one answer to sustainable building construction.

Until relatively recently, green issues were seen as an alternative, a sideline from the mainstream. Now sustainability is the 'new normal', part and parcel of what it means to design and live responsibly and well. Just as we are urged to change our lifestyles to reduce our carbon footprint and consumption of water, there is a great deal we can do to convert our existing homes into greener, healthier places to live.

Within the larger context of low-energy houses we situate as well the steel framed houses. Their specific characteristics and performances are presented further in the thesis.

4. Architectural Design and Solutions for Steel Framed Houses

4.1. Introduction

Chapter 4 analyses the bearing architectural design has on determining building solutions for steel framed houses.

The evolution of iron and steel framed houses shows that the introduction and the acceptance of these structural systems was greatly influenced by historical events and economics.

The architectural solutions for steel framed houses presented further, are grouped into categories, following design elements, such as layout, framing system, envelope and architectural style.

Buildings are judged more often than not by their architectural expression therefore the versatility of steel framed houses to accommodate various architectural styles constitutes a real advantage. Steel framed houses have the potential to support both innovative designs and the capability to incorporate traditional architectural form.

4.2. Evolution of Iron and Steel Framed Houses

An overview of the evolution of iron and steel framed houses, shows the gradual acceptance of metal as a construction material, for the low rise residential sector.

Iron and Timber

The development of construction methods in iron and steel was the most important innovation in architecture since ancient times. These methods provide far stronger and taller structures with less expenditure of material than stone, brick, or wood and can produce greater unsupported spans over openings and interior or exterior spaces. The evolution of steel frame construction in the 20th century entirely changed the concept of the wall and the support.

In architecture before 1800, metals played an auxiliary role. They were used for bonding masonry (dowels and clamps), for tension members (chains strengthening domes, tie rods across arches to reinforce the vaults), and for roofing, doors, windows, and decoration. Cast iron, the first metal that could be substituted for traditional structural materials, was used in bridge building as early as 1779. Its ability to bear loads and to be produced in an endless variety of forms, in addition to its resistance to fire and corrosion, quickly encouraged architectural adaptations, first as columns and arches and afterward in skeletal structures. Because cast iron has much more compressive than tensile strength (for example, it works better as a small column than as a beam), it was largely replaced in the late 19th century by steel, which is more uniformly strong, elastic, and workable, and its high resistance in all stresses can be closely calculated. [35]

Steel structural members are rolled in a variety of shapes, the commonest of which are plates, angles, I beams, and U-shaped channels. These members may be joined by steel bolts or rivets, and the development of welding in the 20th century made it possible to produce fused joints with less labour and materials. The result is a rigid, continuous structure in which the joint is as firm as the member and which distributes stresses between beams and columns. This is a fundamental change in architectural technique, the effect of which cannot yet be estimated. [35]

A framed structure in any material is one that is made stable by a skeleton that is able to stand by itself as a rigid structure without depending on floors or walls to resist deformation. Materials such as wood, steel, and reinforced concrete, which are strong in both tension and compression, make the best members for framing. Masonry skeletons, which cannot be made rigid without walls, are not frames. The heavy timber frame, in which large posts, spaced relatively far apart, support thick floor and roof beams, was the commonest type of construction in eastern Asia and northern Europe from prehistoric times to the mid-19th century. It was supplanted by the American light wood frame (balloon frame), composed of many small and closely spaced members that could be handled easily and assembled quickly by nailing instead of by the slow joinery and dowelling of the past. Construction is similar in the two systems, since they are both based on the post-and-lintel principle. Posts must rest on a level, waterproof foundation, usually composed of masonry or concrete, on which the sill (base member) is attached. Each upper story is laid on crossbeams that are supported on the exterior wall by horizontal members. Interior walls give additional beam support. [35]

Fig. 4.1 - The Iron Bridge on the River Severn , Shropshire, England - 1779

In the heavy-timber system, the beams are strong enough to allow the upper story and roof to project beyond the plane of the ground-floor posts, increasing the space and weather protection. The members are usually exposed on the exterior. In China, Korea, and Japan, spaces between are enclosed by light screen walls and in northern Europe partly by thinner bracing members and partly by boards, panels, or (in half-timbered construction) bricks or earth. [35]

The light frame, however, is sheathed with vertical or horizontal boarding or shingling, which is jointed or overlapped for weather protection. Sheathing helps to brace as well as to protect the frame, so the frame is not structurally independent as in steel frame construction. The light-frame system has not been significantly improved since its introduction, and it lags behind other modern techniques. Prefabricated panels designed to reduce the growing cost of construction have not been widely adopted. Modern heavy-timber and laminated-wood techniques, however, provide means of building up compound members for trusses and arches that challenge steel construction for certain large-scale projects in areas where wood is plentiful. [35]

Steel framing is based on the same principles but is much simplified by the far greater strength of the material, which provides more rigidity with fewer members. The load-bearing capacity of steel is adequate for buildings many times higher than those made of other materials. Because the column and beam are fused by riveting or welding, stresses are distributed between them, and both can be longer and lighter than in structures in which they work independently as post-and-lintel. Thus, large cubic spaces can be spanned by four columns and four beams, and buildings of almost any size can be produced by joining cubes in height and width. Since structural steel must be protected from corrosion, the skeleton is either covered by curtain walls or surfaced in concrete or, more rarely, painted. The steel frame is used also in single-story buildings where large spans are required. The simple cube then can be abandoned for covering systems employing arches, trusses, and other elements in a limitless variety of forms in order to suit the functions of the building. [35]

Differences between reinforced-concrete and steel framing are discussed in the section on materials. The greater rigidity and continuity of concrete frames give them more versatility, but steel is favoured for very tall structures for reasons of economy in construction and space. An example is the system called box frame construction, in which each unit is composed of two walls bearing a slab (the other two walls enclosing the unit are nonbearing curtain walls); this type of construction extends the post-and-lintel principle into three dimensions. Here, again, concrete crosses the barriers that separated traditional methods of construction. [35]

Fig. 4.2 - The Darley Abbey Mill

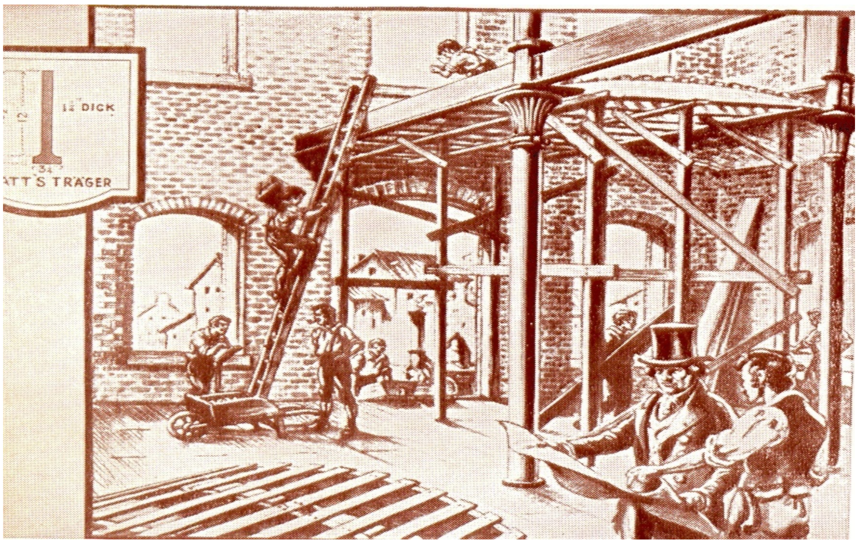


Fig. 4.3 - Matthew Boulton & James Watt- Cotton Mill, Salford UK.1801

The cotton mill of Philip and Lee, built at Salford, Manchester, in 1801, surpasses all others of its time in the boldness of its design. The building is a large one, about 42m long and 12m wide; its height of 7 stories is extraordinary for this early date.

The main structure of the building is composed by a cast-iron skeleton surrounded by outer walls of masonry. The interior framework of the building is composed by secondary iron beams supported by iron columns, representing the first experiment in the use of such elements.

The iron pillars are set on two ranges on each floor. For the first time iron beams of the I- section type are used in combination with iron columns, an example of intuitive recognition of the most efficient shape in advance of the calculations that would prove it to be true. [29]

Prefabricated Iron Frames

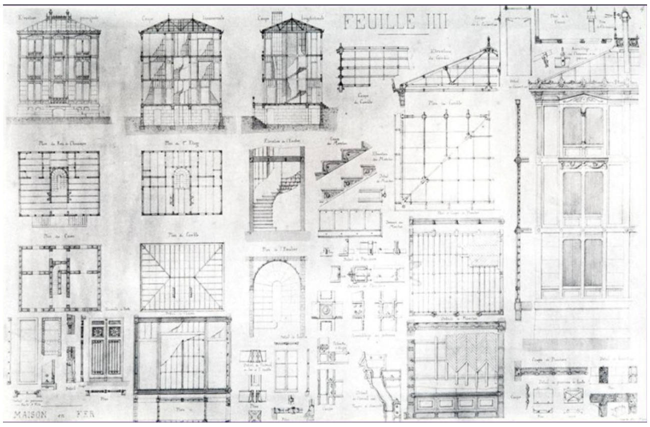


Fig. 4.4 - Louis-Clementin Bruyere -Steel Framed House Project,1852 Ecole Nationale des Beaux-Arts

Fig. 4.5 - Joseph Auguste Duchassaing - Zevallos House, Guadeloupe, 1877

This house was built in the year 1877, by Joseph Auguste Duchassaing for the count Hector Parisis de Zevallos, a sugar tycoon from Guadeloupe, using prefabricated wrought iron frames, exterior masonry walls and ceramic tiles. There are two myths connected to this house, the first one states that it was designed by Gustave Eiffel for a rich person from Louisiana and eventually ended up here, and the second one is that it's a house haunted by the ghost of a former slave.

Fig. 4.6 - Gustave Eiffel - Casa de Fierro, Iquitos, Peru, 1890

The Casa de Fierro in Iquitos is just that—a house made of iron. Gustave Eiffel, the same architect who created the Eiffel Tower, designed the Iron House for the Paris Exhibition in 1889 and it was built by the Belgian workshops of Les Forjes D´Aisseau. Rubber baron Anselmo del Águila bought it and shipped it from Europe during the rubber-boom period. Once dismantled, it was brought in pieces to Iquitos (the metal sheets were carried by hundreds of men through the jungle), and assembled there in 1890.

Casa de Fierro is one of the finest as well as best-preserved samples of civil architecture in Peru. The walls, ceiling, and balcony are plastered in rectangular sheets of iron. It is said to be the first prefabricated house in the Americas. [30]

With the introduction of steel, first for railways and then for building structures, the use of iron was gradually scaled back.

In order to analyse the evolution of steel framed houses, starting with the second decade of the 20th century, we are proposing to consider three types of buildings, characterized by their construction budget and the market they were addressing, as follows:

- Iconic buildings
- Experimental projects
- Mass produced

Iconic Buildings
Frank Lloyd Wright

Fig. 4.7 - Frank Lloyd Wright- Robie House, Chicago, Illinois, 1909

The Robie House, one of the best known examples of Frank Lloyd Wright's Prairie style architecture, made famous by its cantilevered roofs, used a mixed masonry – steel girders system. This is the reason it does not belong completely to the history of steel architecture and it is referred to in reason of its expressive boldness.

Mies van der Rohe

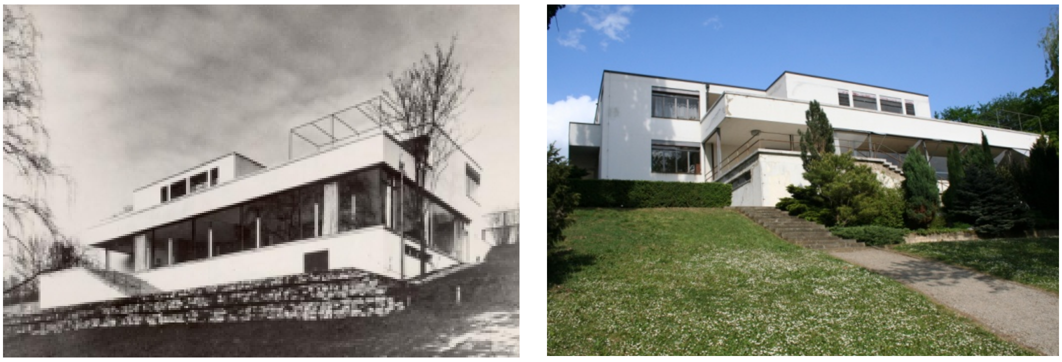


Fig. 4.8 - Steel framed house, Mies van der Rohe – Villa Tugendhat, Brno 1930

Villa Tugendhat is considered a masterpiece, designed by the German architect Ludwig Mies van der Rohe. Built between the years 1928-1930 in Brno, in today's Czech Republic, for Fritz Tugendhat and his wife Greta, the villa soon became an icon of modern architecture.

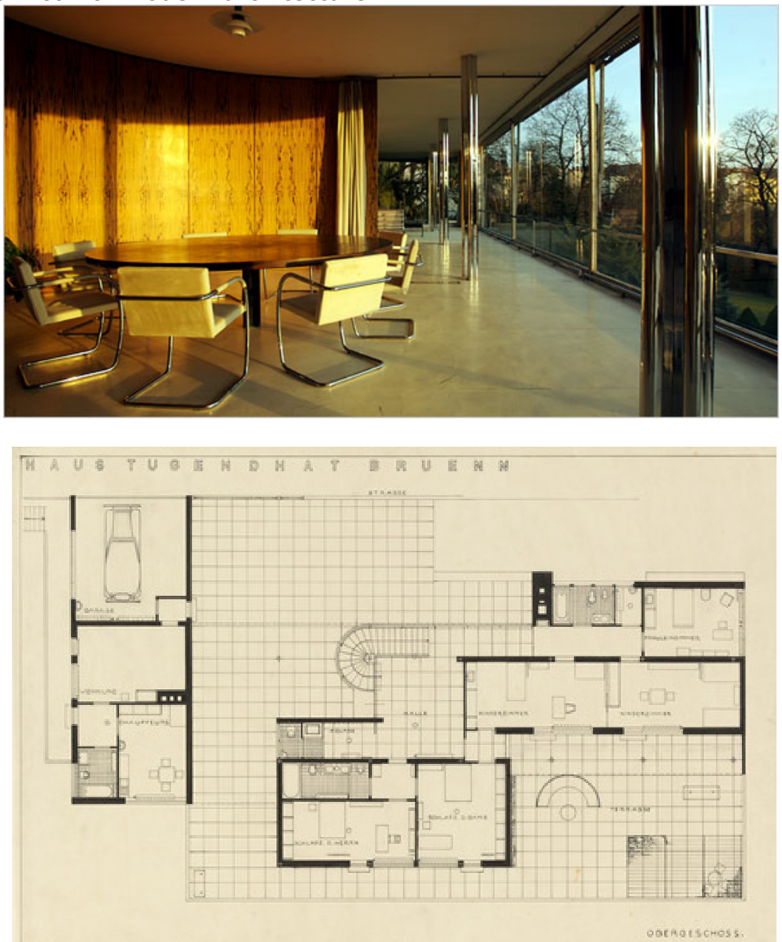


Fig. 4.9 - Villa Tugendhat – plan and interior, Brno 1930

It is a paradigmatic example of functionalism. Mies used the revolutionary iron framework which enabled him to dispense with supporting walls and arrange the interior in order to achieve a feeling of space and light

The free-standing three-storey Villa is situated on a sloped terrain and faces to the south-west.

The house is supported by a huge supporting concrete wall at the site of the street level, thereby creating an expansion between the high edge of the terrain at Černopolní street and the actual structure. The construction of the plastered structure consists of a steel skeleton, reinforced concrete ceilings and brick masonry. The subtle supporting columns of a cross-shaped profile are anchored in concrete bases and partially lead through the masonry and partially through the spaces of all the floors

Fritz and Greta Tugendhat, who were Jewish, left Czechoslovakia with their children in 1938, shortly before the country was dismembered following the Munich Agreement. They never returned. The house was used for various practical purposes for several decades after World War II and in 1992 the political leaders of Czechoslovakia met there to sign the document that formally divided the country into the present separate states of the Czech Republic and Slovakia.

Mies van der Rohe

Fig. 4.10 - Structura metalica in cadre, Mies van der Rohe – casa Farnsworth, 1951

The Farnsworth House was designed and constructed by Ludwig Mies van der Rohe between 1945-51. It is a one-room weekend retreat in a once-rural setting, located 55 miles (89 km) southwest of Chicago's downtown on a 60-acre (24 ha) estate site, adjoining the Fox River, south of the city of Plano, Illinois. The steel and glass house was commissioned by Dr. Edith Farnsworth, a prominent Chicago nephrologist, as a place where she could engage in her hobbies: playing the violin, translating poetry, and enjoying nature. Mies created a 1,500-square-foot (140 m^2) house that is widely recognized as an iconic masterpiece of International Style of architecture.

The essential characteristics of the house are immediately apparent. The extensive use of clear floor-to-ceiling glass opens the interior to its natural surroundings to an extreme degree. Two distinctly expressed horizontal slabs, which form the roof and the floor, sandwich an open space for living. The slab edges are defined by exposed steel structural members painted pure white. The house is elevated 5 feet 3 inches (1.60 m) above a flood plain by eight wide flange steel columns which are attached to the sides of the floor and ceiling slabs. The slabs' ends extend beyond the column supports, creating cantilevers. The house seems to float weightlessly above the ground it occupies. A third floating slab, an attached terrace, acts as a transition between the living area and the ground. The house is accessed by two sets of wide steps connecting ground to terrace and then to porch.

Richard Neutra

Fig 4.11 - Richard Neutra– Kaufmann House, California, 1947

The Kaufmann House, or Kaufmann Desert House, in Palm Springs, California, was one of the last domestic projects conducted by Richard Neutra in 1946, but it is also one of his most famous homes.

The house was an isolated five-bedroom, five-bathroom vacation house in Palm Springs, California, sited on 60 x 90 meter (1200 x 300 foot) plot, designed to enjoy the spectacular views of the surrounding desert and mountains and offering shelter from the harsh climatic conditions.

The house could be one of its kinds at the time, the heaviness of the stone walls being set off large areas of glass; it was also a model of sophisticated design by today's standards, fully energy conscious and environmentally friendly design, the roof overhangs and lows adjustably with an under floor heating and cooling system combined to provide comprehensive and unobtrusive climate control. Around the house Richard Neutral created a natural garden of indigenous rocks and cacti this was to prove even more that the building is connected to its surrounded desert landscape.

To give greater visibility to the renowned quality of "floating" in the design, the structural system combines wood and steel so that the amount of vertical supports necessary, limited in any case, is reduced. This is particularly evident in the living room, whose walls of steel and glass slide outward toward the southeast, while the construction of deck and supports the hanging wall sliding moving toward the pool and spatially linking the house with it. This radial arm became the hallmark of Neutra, is the "spider leg," the umbilical cord that merges space and building.

Pierre Chareau

Fig. 4.12 - Pierre Chareau - Glass HouseParis,1932

Constructed in the early modern style of architecture, the house's design emphasized three primary traits: honesty of materials, variable transparency of forms, and juxtaposition of "industrial" materials and fixtures with a more traditional style of home décor. The primary materials used were steel, glass, and glass block. Some of the notable "industrial" elements included rubberized floor tiles, bare steel beams, perforated metal sheet, heavy industrial light fixtures, and mechanical fixtures.

The house is notable for its splendid architecture, but it may be more well-known for the fact that it was built on the site of a much older building which the patron had purchased and intended to demolish. Much to his or her chagrin, however, the elderly tenant on the top floor of the building absolutely refused to sell, and so the patron was obliged to completely demolish the bottom three floors of the building and construct the Maison de Verre underneath, all without disturbing the original top floor.

Phillip Johnson

The Glass House or Johnson house, built in 1949 in New Canaan, Connecticut, was designed by Philip Johnson as his own residence and is a masterpiece in the use of glass. It was an important and influential project for Johnson and his associate Richard Foster, and for modern architecture. The building is an essay in minimal structure, geometry, proportion, and the effects of transparency and reflection.

Fig. 4.13 - Phillip Johnson – Johnson House, New Canaan, Conn. 1949

The house is an example of one of the earliest uses of industrial materials like glass and steel in home design.

The building is 56 feet (17 m) long, 32 feet (9.8 m) wide and 10½ feet high. The kitchen, dining and sleeping areas were all in one glass-enclosed room, which Johnson initially lived in, together with the brick guest house (later the glass-walled building was only used for entertaining). The exterior sides of the Glass House are charcoal-painted steel and glass. The brick floor is about 10 inches above the ground. The interior is open with the space divided by low walnut cabinets; a brick cylinder contains the bathroom and is the only object to reach floor to ceiling.

Werner Sobek

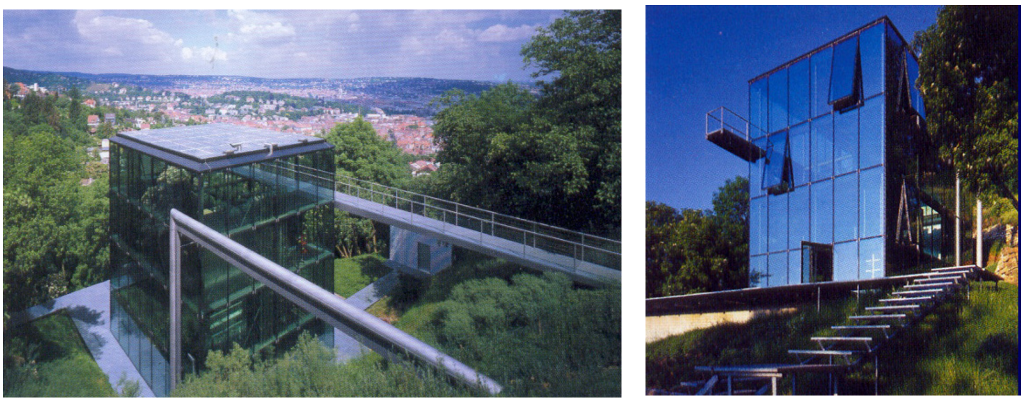


Fig. 4.14 - Structura metalica in cadre, Werner Sobek – casa Sobek, Stuttgart 2000

This four-storey building which was erected in 1999-2000, occupies a steep parcel of land on the edge of the bowl-shaped vale of Stuttgart. It was designed as a completely recyclable building which produces no emissions and is self -sufficient in terms of heating energy requirement. The completely glazed building has high *quality* triple glazing panels featuring a k-value of 0.4. Because of its assembly by means of mortice-and-tenon joints and bolted joints, it cannot only be assembled and dismantled easily but is also completely recyclable. The electrical energy required for the energy concept and control engineering is produced by solar cells.

Access to the building is via a bridge leading to the top floor. This level accommodates the kitchen and dining area. The two levels below successively provide a living and sleeping area; the bottom level accommodates the nursery as well as the technical and utility installations. Each of the four levels is defined by a few pieces of furniture, repeating the concept of maximum transparency in the interior of the building as well. [34]

The load-bearing structure of the building consists of a steel frame stiffened by diagonal members and erected on a reinforced concrete raft. The floors consist of heavy-section timber modules. All load-bearing and non-loadbearing elements as well as the facade are of modular design and assembled using easily separable methods of jointing. There is neither rendering or screeding, eliminating any compound materials which may be difficult or impossible to dispose of. For this reason there are no cables or pipes embedded in the walls. All supply or disposal systems as well as communication lines are housed in metal ducts which run along the facades and are built into the floor / ceiling structures. [34]

To enable the house to be built as an emission-free zero-heating-energy house, an innovative computer-controlled energy concept was developed which can be checked by telephone or computer from any place on earth. The heat energy radiated into the building by the sun is absorbed by water-filled ceiling panels and transferred to a heat store from which the building is heated in the winter by reversing the heat exchanging process. In this mode the ceiling panels function as heat radiators; additional heating is not needed. [34]

Experimental Projects

The Bauhaus Steel Framed House [31]

In Europe, the devastation of World War I and the surplus of steel that followed its end led architects to prefabricate systems of concrete and steel for housing developments and single family residences.

In 1923, Walter Gropius and Adolf Meyer developed a "building block" system of standardized flat roof housing and designed a construction system for the Toerten-Dessau housing system. These modern innovations heralded a new era of mass-produced homes that would do away with "dead concepts in regard to the house" and helped to inspire the International Style of architecture.

The problem that eluded most architects and designers at the time was how to manufacture prefabricated housing on a large scale. Le Corbusier and the Bauhaus architects knew that automation and assembly line were key components, but they lacked both the means and manufacturing expertise.

The automobile and aircraft industries, equipped with machines, factories, and skilled workers, were best suited for the production of prefabricated houses.

Walter Gropius had long been fascinated by the possibilities of applying innovative techniques to create mass-produced housing kits. While Sears was equipping its traditional homes with precut timber frames and historical flourishes,

Gropius, as early as 1910, had begun to think about factory-prefabricated houses made from industrial materials such as steel.

Fig. 4.15 - Bauhaus Experiment, Georg Muche &Richard Paulik, Dessau – 1926

The Steel House in Dessau was constructed as a prototype for rationalized housing projects, based on the potential of steel construction. Therefore architect Muche believed that systems-building was the only possible continuation of building with bricks and stones. This steel house follows his 'House on the Horn' in Weimar, erected three years earlier. The Steel House's construction consists of H-beams from which 3-mm steel sheets were suspended. Two interlocking cubes with horizontal façades were designed. Room-high doors and big, vertical windows provide the living rooms with lightness, whereas the subsidiary rooms are lit by bull´s-eye-openings. The architects created several color schemes for the building, but the ultimate grey-white-black version might be regarded as a result by Walter Gropius´ influence.

Jean Prouve

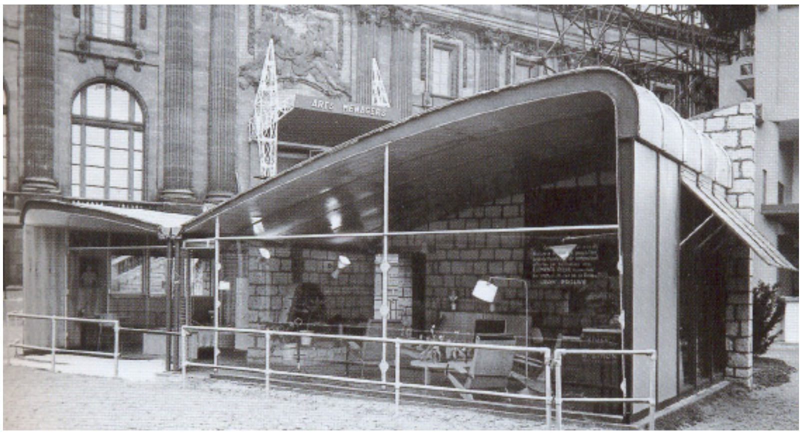


Fig. 4.16 - Jean Prouve –Maison Coques, 1951

In France, Jean Prouvé developed prototypes for prefabricated houses using light-weight structural frames and industrial cladding systems, and some were mass-produced.

In 1947 he opened a workshop at Maxéville, and he employed more than 200 people. Here he undertook extensive research on the uses of aluminium and he developed a lightweight metallic building system intended to construct schools, vacation camps, and other public buildings, as well as housing.

Among his achievements at Maxéville was the Tropical House—perhaps the ultimate iteration of his lightweight metal building system.

In 1949, Prouvé was given a contract by the Ministry of Reconstruction and Urbanism to build a 14-lot subdivision at Meudon, just outside Paris, to demonstrate his prototype lightweight prefabricated metal building system.

The same year, the idea of exporting a tropical variant was suggested by architects Paul Herbé and Jean Le Couteur. The two government urbanists had been posted to Africa and were suffering at night from the heat retained by their concrete lodgings. Prouvé obtained an order for the first Tropical House prototype, destined for Niamey, Niger, and collaborated with Herbé and Le Couteur on the design of a series of unbuilt public works for Niamey and Ouagadougou (in present-day Burkina Faso).

Fig. 4.17 - Jean Prouve –Maison Tropicale, Brazzavile, Congo, 1949 Steel Prefabricated Frames

Two more houses were commissioned by the African marketing arm of the French aluminum monopoly and installed in Brazzaville, capital of the Congo, in 1951.

The Tropical House sat on a simple one-meter grid system with fork-shaped portico supports of bent steel, honoring Prouvé's dictum to build using the smallest possible number of parts. All but the largest structural elements were aluminum, and everything was as flat as possible to fit inside a cargo plane.

To cope with the extremes of the tropical climate, the outer light-reflecting skin consisting of brises soleils that shielded the structure from direct sunlight, was separated from the inner insulating of sliding doors and fixed panels. The floor was suspended above a locally made base to control humidity, and the ventilation chimney in the center allowed warm air to escape. The original house constructed in Brazzaville measured 33 by 46 feet, including its veranda, and was outfitted with movable room dividers, a bathroom, and a kitchen.

In the U.S., steel-frame construction and offthe-shelf materials were used in many of the Case Study Houses. The Case Study program was initiated by John Entenza, the editor of Art & Architecture, to promote the design of modern houses that were "simple in plan, modulated in structure, classically ordered in aesthetic."

While the Case Study Houses were never mass-produced, architects such as Elwood and Koenig were committed to the ideal of producing affordable, prefabricated houses. In 1956 Craig Ellwood noted that "More and more the increasing cost of labor is moving construction to the factory."

His Case Study House #17 of 1956 has a U-shaped plan organized around a pool. It uses a structural frame composed of 4-inch H-columns and 5-inch I-beams. The infilling between columns is 8-inch clay block and glass. The clay block was chosen for its cost and "the natural beauty of the burned red clay…the high-density strength, weatherproofing, and modular dimensions for ease of design detail and construction."

Charles Eames

The glass-and-steel houses designed by Charles and Ray Eames, Eero Saarinen, Craig Elwood, and Pierre Koenig are the most well-known. Both the Entenza House of 1945, designed by Charles Eames and Saarinen, and the Eames House of 1949, designed by Charles and Ray Eames for themselves, used standardized industrial materials to create playful juxtapositions between indoor and outdoor spaces designed for living and working.

Fig. 4.18 - Case Study House #8, Charles Eames –Eames House, Pacific Palisades, Ca., 1949

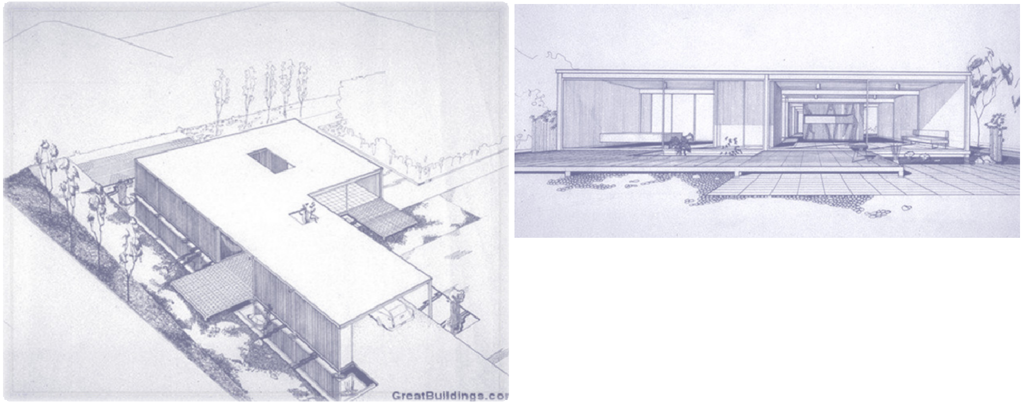


Fig. 4.19 - Case Study House #21, Pierre Koenig – West Hollywood ,Ca., 1958

Koenig's Case Study House #21 of 1958, for example, eschews 4-foot and 8-foot modules for bay sizes of 10 and 22 feet wide and 9 feet high. The governing factor in his design was "economy, not only in cost, but in variety of materials." The frames were shop fabricated and delivered to the site in one piece. He believed in using pre-fabricated mono-planar walls and placing utilities underground.

Fig. 4.20 – Case Study House #22, Pierre Koenig – Stahl House,
West Hollywood ,Ca., 1960

The Case Study House Program produced some of the most iconic architectural projects of the 20th Century, but none more iconic than or as famous as the Stahl House, also known as Case Study House #22 by Pierre Koenig. The glass and steel construction is understandably the most identifiable trait of architectural modernism.

The house is "L" shaped in that the private and public sectors are completely separated save for a single hallway that connects the two wings. Compositionally adjacent is the swimming pool that one must cross in order to get into the house; it is not only a spatial division of public and private but its serves as the interstitial space that one must pass through in order to experience the panoramic views. The living space of the house is set back behind the pool and is the only part of the house that has a solid wall, which backs up to the carport and the street. The entire house is understood to be one large viewing box that captures amazing perspectives of the house, the landscape, and Los Angeles.

The Stahl house was a residential engineering feat because it is cantilevered over the rocky hillside that it is built on, and at the time it was one of the first houses in West Hollywood to be built using a steel frame. Pierre Koenig was given an award by the American Iron & Steel Institute for the use of structural steel in a private resident construction.

Mass Produced Steel Framed residential Buildings

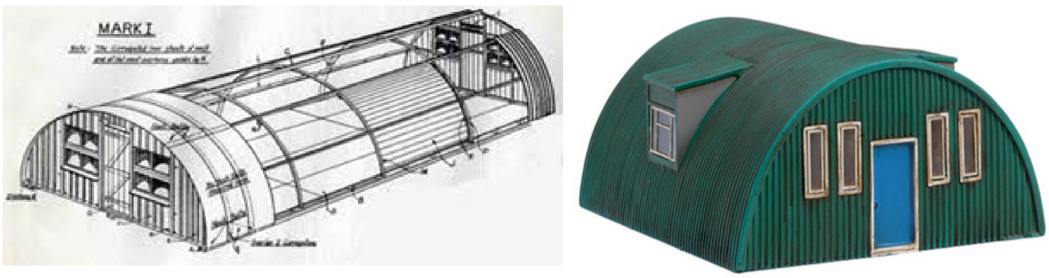


Fig. 4.21 - Peter Norman Nissen - Nissen hut - 1916

Between April 16 and April 18, 1916, Major Peter Norman Nissen of the 29th Company Royal Engineers began to experiment with hut designs. Nissen, a mining engineer and inventor, constructed three prototype semi-cylindrical huts. After the third prototype was completed, the design was formalized and the Nissen hut was put into production in August 1916. At least 100,000 were produced in World War I.

Two factors influenced the design of the hut. First, the building had to be economical in its use of materials, especially considering wartime shortages of building material. Second, the building had to be portable. This was particularly important in view of the wartime shortages of shipping space. This led to a simple form that was prefabricated for ease of erection and removal. The Nissen hut could be packed in a standard Army wagon and erected by six men in four hours. The world record for erection was 1 hour 27 minutes. [30]

A Nissen hut is made from a sheet of metal bent into half a cylinder and planted in the ground with its axis horizontal. The cross-section was not precisely semi-circular, as the bottom of the hut curved in slightly. The exterior was formed from curved corrugated steel sheets (3.2 × 0.7 m), laid with a two-corrugation lap at the side and a 15 cm overlap at the ends. Three sheets covered the arc of the hut (about 54 sheets in all were required). These were attached to five 7.5 x 5 cm wooden purlins and wooden spiking plates at the ends of the floor joists. [30]

The purlins were attached to eight T-shaped ribs (4.5 × 4.5 × 0.5 cm) set at 1.8 m centres. Each rib consisted of three sections bolted together using splice plates, and each end was bolted to the floor at the bearers. With each rib were two straining wires, one on each side and a straining ratchet (or in some cases a simple fencing wire strainer). The wires were strained during construction. Interior lining could be horizontal corrugated iron or material like Masonite attached to the ribs.

The space between the interior and exterior lining could be used for insulation and services, if required. [30]

The walls and floors rested on foundations consisting of 10 × 10 cm stumps with 38 × 23 cm sole plates. On these were 10 × 8 cm bearers and 10 × 5 cm joists at 1 m centres. The floor was made from tongue and groove floorboards or from concrete, in this case the ribs were simply attached to the concrete slab by a metal strap. At either end the walls were made from a wooden frame with weatherboards nailed to the outside. [30]

Nissen huts come in three internal spans —4.9 m, 7.3 m or 9.2 m. The longitudinal bays come in multiples of 1.8. The corrugated steel half-circles used to build Nissen huts can be stored efficiently, because the curved sheets can be cupped one inside another.

Although the prefabricated hut was conceived to meet wartime demand for accommodation, similar situations, such as construction camps, are places where prefabricated buildings are useful. The Nissen hut was adapted into a prefabricated two-storey house and marketed by Nissen-Petren Ltd. The standard Nissen Hut was often recycled into housing. [30]

Fig. 4.22 – The Nissen hut adapted into a prefabricated house

Accounts of life in the hut generally were not positive. Huts in the United Kingdom were frequently seen as cold and draughty, while those in the Middle East, Asia and the Pacific were seen as stuffy and humid.

Nonetheless, 50 Nissen huts were constructed in North Belmont, a suburb of Newcastle in New South Wales, Australia after World War II. They were designed to provide cheap, ready-made housing for post-war British migrants families. While 17 of the huts were eventually demolished, the remainder have been refurbished, improved and extended over time, and remain popular with their owners. Currently, there are attempts to have the remaining cluster of huts declared as a conservation area, with the objective of assisting in their preservation.

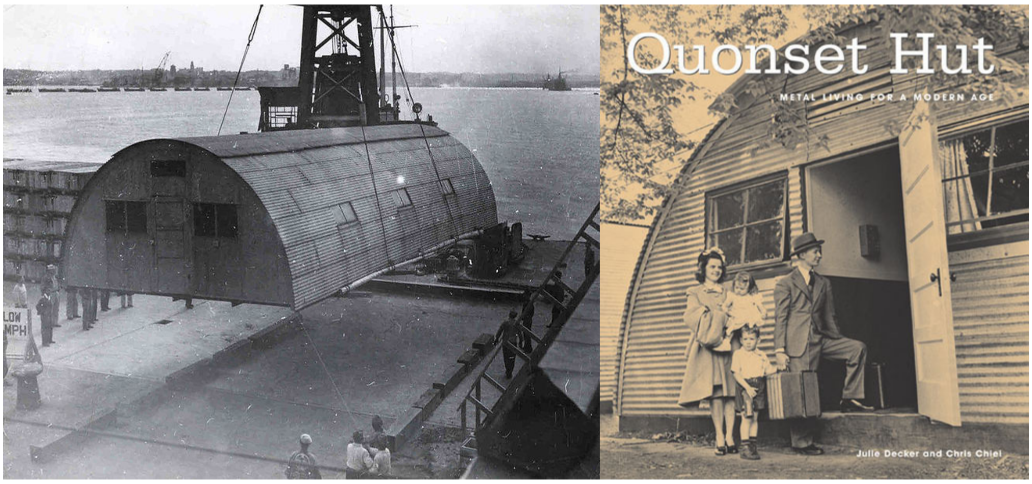


Fig. 4.23 - Quonset Hut, British Army, WWII

In 1941 the United States Navy needed an all-purpose, lightweight building that could be shipped anywhere and assembled without skilled labor. The answer was the Quonset hut, a lightweight prefabricated structure of corrugated galvanized steel having a semicircular cross section. The design was based on the Nissen hut developed by the British during World War I. [30]

The original design was a 5 × 11 m structure framed with steel members with a 2.4 m radius. The sides were corrugated steel sheets. The two ends were covered with plywood, which had doors and windows. The interior was insulated and had pressed wood lining and a wood floor. The building could be placed on concrete, on pilings, or directly on the ground with a wood floor.

Between 150,000 and 170,000 Quonset huts were manufactured during World War II. After the war, the U.S. military sold the surplus Quonset huts to the public for $1,000 each—this approached the cost of a small home. Many are still standing throughout the United States. Besides those that remain in use as outbuildings, they are often seen at military museums and other places featuring World War II memorabilia. [30]

However, the adaptation of the semi-cylindrical hut to non-institutional uses was not popular, despite articles on how to adapt the buildings for domestic use appearing in *Home Beautiful* and *Popular Mechanics*. Neither the Nissen, nor the Quonset developed into popular housing, despite their low cost. One reason was the association with huts: A hut was not a house, with all the status a house implies. The second point was that rectangular furniture does not fit into a curved wall house very well, and, thus, the actual usable space in a hut might be much less than supposed. [30]

Fig. 4.24 - Lustron Corporation-family home, USA, 1948, prefabricated, all-steel house

Many mass-produced house have been designed in a manner similar to the Sears Ready-Cut House, a made-to-order kit-of-parts that could be assembled on site. In 1948, the Lustron Corporation began producing prefabricated, all-steel houses in a surplus wartime aircraft factory. The low maintenance enamel finish was expected to attract modern families who might not have the time or interest in repairing and painting conventional wood and plaster houses.

Their sturdy steel frame was constructed on-site by a team of local workers who assembled the house piece-by-piece from a special Lustron Corporation delivery truck. The assembly team, who worked for the local Lustron builder-dealer followed a special manual from Lustron, and were supposed to complete a house in 360 man-hours. In most models, the homes were heated with an oil burning furnace that directed hot air into an enclosed space above the metal ceilings. The walls contained a one inch blanket of fiberglass wool insulation. The decorative "zig-zag" accent is unique to Lustron homes.

The company was not able to market it for appreciably less than a conventional house. After all, a Lustron required over 3,000 component parts totaling over 12 tons of steel for each house. Consequently, only 2,500 Lustron homes were built before the company folded in 1950. Production delays, the lack of a viable distribution strategy, and the escalating prices for the finished product all contributed to the failure.

It was not until just after the First World War, when the replacement and renewal of housing was a big issue, that the use of pre-fabrication for house building in the UK developed in a serious or significant way. The building industry was seriously affected by a shortage of skilled labour and essential materials, industrial capacity and manpower having been diverted into the war effort. The result was an acute housing shortage and, in order to alleviate it, a number of new methods of construction were developed. This led, for example, to the production of more than twenty steel framed housing systems.

Fig. 4.25 Telford steel framed house -1920s- steel clad systems

The Dorlonco system is considered to be the most successful of the post-WWI house types, in terms of both commercial viability and longevity of production, with some examples dating from post-WWII period. Originally built to house workers and their families of the Dorman Long Company at Dormanstown, the first demonstration houses were built in 1919 and the system received the support of the Ministry of Health. The system appears to have been well designed to avoid problems of corrosion in the main structure, whilst the close spacing of the steel framework made a secondary timber framework to support claddings and linings unnecessary. The steel frame was designed to accept a number of different claddings, from conventional brickwork to render on a metal lath.

Fig. 4.26 Adshead, Ramsey and Abercrombie – Dorlonco house system

The system's architects, Adshead, Ramsey and Abercrombie, created a well proportioned house that conformed to the popular neo-Georgian style. The regular sizing and placement of window and door openings satisfied the expectation of standardisation and simplification that had become an orthodoxy during the war years, and was also well suited to systemised building. Internal linings are very robust, consisting of a 2 inch thick leaf of clinker block work, plastered on the inner face, whilst intermediate floors are of concrete on metal lath reinforcement. As a result, the houses give the impression of being extremely solidly built. The Dorman Long Company was responsible for the manufacture and erection of the steel frame, the completion of the houses being carried out by local contractors or Local Authority direct labour.

In the years immediately following World War II, Japan faced a serious housing crisis that required the fastest construction possible of four million new homes. Prior to 1940, most commercial and residential buildings were made of wood, but they were destroyed during the war. After World War II, Japan did not have the wood to replace these houses--that would have required 150 years worth of timber growth. So, Japan turned to readily available--and non-flammable--steel, and the steel housing market was born.

The Japanese steel industry developed and manufactured light-gauge steel components that mimicked the shapes and sizes of traditional lumber, and these were successfully used in new home construction frames. These designs quickly gained favor and have been improved over the years, resulting in a constant rise in constructional steel housing around the world.

Following the success of steel-frame homes in Japan, the United Kingdom housing market turned to readily available metal- and steel-building materials. Today, several of the top 20 home building companies there use steel-frame construction for new flats and two-story homes.

The British Iron and Steel Federation, an association of steel producers, was formed in 1934 in order to provide central planning for the industry. It was prominent in coordinating output through the War, and sponsored a solution for permanent steel framed housing to a design by architect Sir Frederick Gibberd. Gibberd's office also designed the steel framed Howard House, privately promoted by John Howard & Company. Both designs were assessed and approved for development by the Burt Committee (1944), and subsequently 36,000 BISF houses and 1,500 Howard Houses were built.

The comparison these two house types is of interest because, though the designs are from the same stable, they demonstrate different approaches to innovation and the expression of new methods. The BISF is the more conventional of the two, technically and aesthetically. The simple architectural devices of projecting window surrounds and differing cladding to the upper and lower stories deal with the junction between components in an understated fashion. Traditional materials could be incorporated or simulated, for example a brick cladding to the lower storey, or steel sheet profiled to match timber weatherboarding to the upper.

The BISF house also uses tried and tested methods, with a simple over-site slab ground floor and render on metal lath cladding. By comparison, the Howard House has a more industrial aesthetic and was more adventurous in its use of innovative technologies. Asbestos cement cladding panels are clearly expressed with metal flashings over a base course of foamed slag concrete panels, with windows and doors fitting within the module set up by the cladding. Unlike the BISF this house proudly displays its lightweight prefab nature, but there are also technical advances that set the Howard House apart, for example the pre-cast concrete perimeter plinth that supports a suspended steel ground floor.

Fig. 4.27 The British Iron and Steel Federation House (BISF)

It seems likely that the BISF house, with its more conventional proportions and solid appearance, would have appealed more directly to popular taste than the Howard, but this is not the main reason for its comparative success. The British Steel Homes company, producers of the BISF house, also benefited from the support of the British Iron and Steel Federation, which could ensure a supply of the material at a time when conventional methods were returning to profitability and steel was in demand again due to cold-war rearmament. The BISF also benefited from a guaranteed order of 30,000 given by the Government in 1941.

Neither house, however, could endure beyond the combined effect of the reorganisation of the steel industry (including a short- lived nationalisation in 1951), and a Conservative party election pledge to build 300,000 houses, which could only be met by lowering standards and cutting costs in public housing

Australia also favors steel-frame housing for new residential developments, and general contractors and project managers in that country often use the same successful designs on multiple projects. Scandinavian builders use steel- and metal-frame construction for affordable apartment communities and incorporate other unconventional materials, including mineral wool and gypsum board.

The United States utilized steel and metal framing for commercial structures and office buildings for many years before embracing the concept for residential construction. New affordable home construction in the United States is now comprised of 20 percent steel-frame houses. In the past 15 years, the steel- and metal-frame housing marketing has been a boon to the residential construction industry.

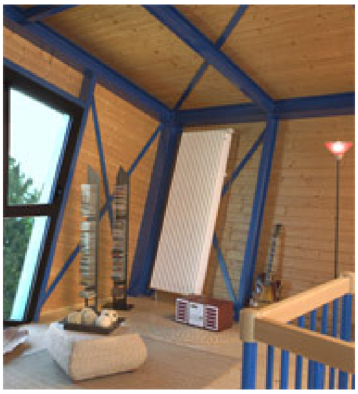


Fig. 4.28 The Ruginello row houses Roccatelier Associatti

Fig. 4.29 - M. De Kulesza – Le Castel Row Housing, Levarde, France, 1988

This 35 unit row housing project was built in France in 1988. The structure is made out of prefabricated panels using lightweight profiles, factory assembled. Floors are steel deck and concrete and the roof structure is made of light metal frames. The envelope is made out of corrugated steel. The construction project was finished in 6 months.


Fig. 4.30 - Martin Cleffmann – Row Housing, Ger., 1995

The row houses designed by the German architect Martin Cleffmann, are very good illustration of the fact that steel framed structures provide an excellent support system for innovative architectural expression.

Fig. 4.31 RATIO:n:ING – Avila Row Housing

This project, developed by RATIO:n:ING, consisted of the construction of 28 row houses in the department of Avila, a territory with extreme temperatures lying in the centre of Spain.

Two main types of house were designed; Type A (16 units) with a surface of 140 sqm, and Type B (12 units) with a surface of 160 sqm. Both types had two floors and a flat roof.

All the walls were built with lightweight steel frames, preassembled in client's facilities, and erected over a concrete foundation. Also the roof was made of light gauge steel beams. The floor structure, due to client wishes, was made of a composite structure (trapezoidal steel sheet + reinforced concrete).

As recently as the 1990s, very few steel frame houses were built in the United States, but the trend has dramatically increased. Because steel-frame homes are termite proof, fire resistant and highly energy efficient, the market share for steel- and metal-frame homes has increased every year.

Since the structural steel materials have such low levels of waste and are largely comprised of recycled steel, this type of housing has been embraced by environmentalists and economists, ensuring its popularity for the foreseeable future. Many companies are exploring lighter steel frame options as well as alternative construction methods. Each day also brings new standardized blueprints and plans for steel homes, solidifying their future in tomorrow's housing market.

4.3. Architectural Solutions for Steel Framed Houses

Pier Luigi Nervi said:

'A technically perfect work can be aesthetically inexpressive but there does not exist, either in the past or the present, a work of architecture which is accepted and recognised as excellent from the aesthetic point of view which is not also excellent from the technical point of view. Good engineering seems to be a necessary though not sufficient condition for good architecture.'

Architectural Solutions Defined by Structural System

The distinct advantages of the use of steel in modern building construction may be summarised as follows:

- The modular nature of its fabrication (a 'kit of parts'), which can be delivered 'just in time' to site when required.
- The potential for rapid erection of the framework on site, which also reduces local disruption, noise and site storage.
- It is prefabricated to a high degree of accuracy.
- Long spans can be achieved economically by a variety of structural systems in steel and composite construction, permitting greater usable space.
- Steel or composite frames are lighter than concrete frames of the same span, thus reducing foundation costs.
- Steelwork permits adaptation in the future, and components can be re-used by unbolting.
- Composite steel-concrete floors can contribute to a thermally efficient building.
- A high proportion of steel production is recycled from scrap, and all steel is recyclable [64]

Lightweight Stud Framing

The lightweight stud framing system is widespread today on all continents. Developed originally on the experience accumulated in timber frame building construction, the system bears remarkable similarities with wood stud construction.

Fig. 4.32 Typical north-american contractor house

The lightweight stud framing allows for a variety of volumetric solutions, ranging from the neo-vernacular to the most modern architectural expression. In terms of layout flexibility, the system has its limitations, in terms of spans and allowable wall openings.

Fig. 4.33 Lightweight house structure for Lindab Romania, Britt Eng.

In terms of envelope design compatibility, the lightweight stud system is ideal, offering multiple ways for fastening the successive wall layers.

Fig. 4.34 Lightweight stud construction, B. House, Britt Eng

Hot Rolled Framing

A framework is a three-dimensional assembly of steel members that form a self-supporting structure or enclosure. The most common and economic way to enclose a space is to use a series of two- dimensional frames that are spaced at equal intervals along one axis of the building Stability is achieved in the two directions by the use of rigid framing, diagonal bracing, or through the supporting action of concrete shear walls or cores. This method of 'extruding' a building volume is equally applicable to any frame geometry, whether of single or multiple bays.

Three-dimensional frames can vary enormously in overall form, in the overall geometry of the individual members comprising them, and in the elements comprising the horizontal and vertical members. In these more complex frames, elements may be repeated, but the structure relies for its effectiveness on mutual support in three dimensions. Multi-storey building frames comprise beams and columns, generally in an orthogonal arrangement. The grillage of members in the floor structure generally comprise secondary beams that support the floor slab and primary beams that support the secondary beams. The primary beams tend to be heavier and often deeper than the secondary beams.

The fundamental structural requirement governing the design of connections in building frames is related to the strength and stiffness of the connections between the members, or of members to the foundations.

The connections may be one of three configurations defining these degrees of strength (or more correctly 'resistance') and stiffness :

1. Rigid, also called moment-resisting, connections
2. Pinned, also called simple, connections
3. Semi-rigid, also called partial strength, connections

Rigid frames require rigid connections in order to provide for stability at least in one direction. Braced frames are stabilised by vertically oriented bracing, and require only pinned connections. Rigid frames are often termed 'sway frames', because they are more flexible under horizontal loads than braced frames.

In a 'rigid' connection there is complete structural continuity between any two adjacent members. Moment (or rigid) connections are used in frames where there is a desire to omit vertical bracing in one or both directions. The main advantage of rigid frames is that an open space between columns can be created, which offers flexibility in choice of cladding, etc. (e.g. in glazed façades). However, the achievement of full continuity between members at the connection requires an extensive amount of fabrication and, as a consequence, this system is relatively expensive

To achieve a nominally 'pinned' joint, the connections are made so as to permit the transfer of axial and shear forces, but not bending moments. Nominally simple connections may provide some small degree of rigidity, but this is ignored in structural design and these connections are treated as pinned.

Pinned connections are usually simple to fabricate and erect, and are the least expensive type of connection to produce. As a consequence, lateral stiffness must be introduced into the frame by other means.

Semi-rigid (and also partial strength) connections achieve some continuity through the connections, but are not classified as full strength, as they do not achieve the bending resistance of the connected members. They are used for low-rise frames in which horizontal forces are not so high, or in beams where some end fixity is beneficial to the control of deflections.

The use of hot rolled framing used in low rise residential design comes usually as a response to the calls for building efficiency. Indeed, the relative cost increase induced by the use of hot rolled framing, as compared to lightweight stud construction, is offset by lower labor costs and increased speed in execution.

The connections may be one of three configurations defining these degrees of strength (or more correctly 'resistance') and stiffness:

1. Rigid (also called fixed or moment-resisting) connections
2. Pinned (also called simple) connections
3. Semi-rigid (also termed partial strength) connections.

Rigid frames require rigid connections in order to provide for stability at least in one direction. Braced frames are stabilised by vertically oriented bracing, and require only pinned connections. Rigid frames are often termed 'sway frames', because they are more flexible under horizontal loads than braced frames.

Fig. 4.35 Hot rolled frame, Mihai Mutiu, arch., P House, Timisoara, Romania, 2011

In terms of layout flexibility, the use of hot rolled framing presents a number of advantages, ranging from increased spans and large wall openings. On top of this, the architectural expression can be pushed to the limit through cantilevers and roof overhangs.

Fig. 4.36 Space Group Architects, Oslo, Norway, 2003

In order to support an envelope, a secondary structural system (wall structure) is required. Such structures are usually made out of lightweight studs and constitute the frame on which the successive envelope layers are fastened.

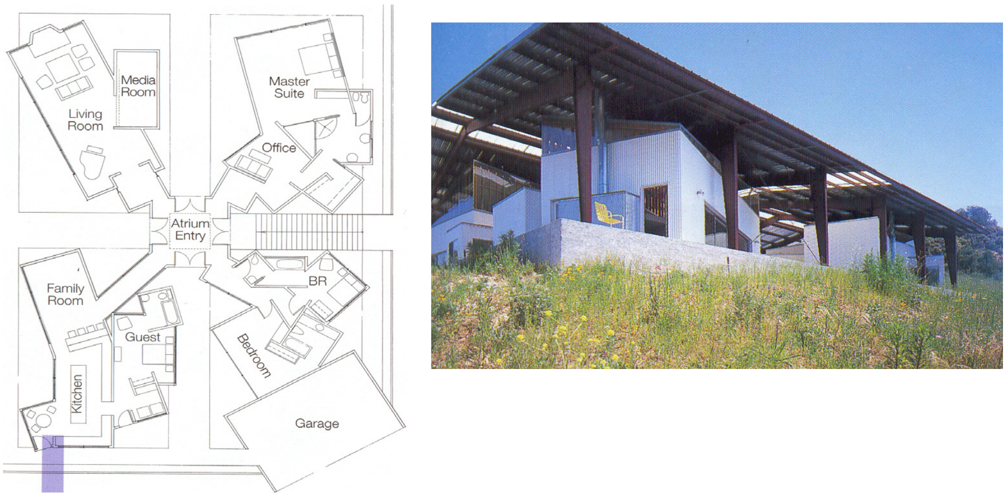


Fig. 4.37 Hot rolled frame, Brian Murphy, arch. Topanga Canyon,L.A., 1998

Mixed Steel-Wood Framing

The mixed steel-wood framing system consists in the use of two materials which through their specific characteristics, complement very well each other. The basic principle is to replace the lightweight studs of the secondary wall structure, with wood studs as is timber framed construction.

This has the effect of reducing construction costs and improving the overall insulating quality of the envelope.

Fig. 4.38 DM House – mixed steel wood structure

In the mixed steel-wood structures, wood studs can successfully replace secondary beams or steel decks, for floor construction.

Exposed structural frames

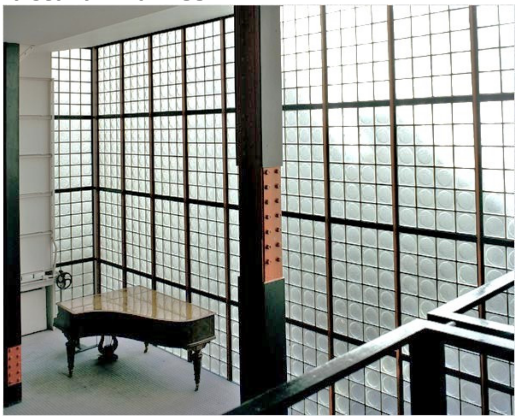


Fig. 4.39 Pierre Chareau - Glass House - Paris,1932

Fig. 4.40 Rocca Atelier Associatti - Ruginello row houses project

Fig. 4.41 Arthur Erickson - Balboa Beach House, at Malibu, California, 1988

Architectural Solutions Defined by Envelope

Steel framed houses are widespread throughout the world in a variety of climatic conditions. If the structural systems per se are very similar, envelope design has to specifically address local conditions.

In general, due to cost considerations, envelopes are designed as single envelopes. Double envelopes are usually not specified for the average budget house.

In terms of architectural expression, the exterior layer of the envelope, the cladding, is the most important, as it situates stylistically the building.

In cold climates, the specific conditions call for compact volumes, over-insulation, triple glazing and extra care in solving thermal bridging.

Typical cladding materials could be:

wood/shingles siding, vinyl siding, metal siding, brick veneer, stone veneer

Fig. 4.42 Examples of wood siding and shingles

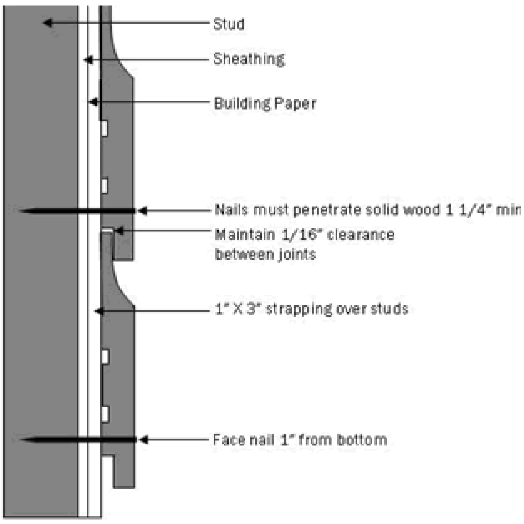


Fig. 4.43 Wood siding detail

Fig. 4.44 Reclaimed wood cladding

A simple, archetypal form is used in this example build in 2009 in the Sudety region of Poland, by architect Tomasz Glowacki. The house illustrates a new architectural expression for the isolated house typology, by making an explicit reference to a rural model.

Fig. 4.45 PAG Architects - Pracownia Broken Barn, 2009

Starting from a box with a pitched roof, PUG explores an architectural composition, characterized by a fragmented assemblage of building wings, allowing a visual recuperation of the attic space and a logic re-evaluation of gable roof expressivity. [67]

Fig. 4.46 Einar Jarmund Architect – The Red House, Oslo, 2002

The temperate maritime climates of Western Europe for example, are specific to countries which pioneered residential steel framed construction, such as Germany, Scandinavian Countries or UK.

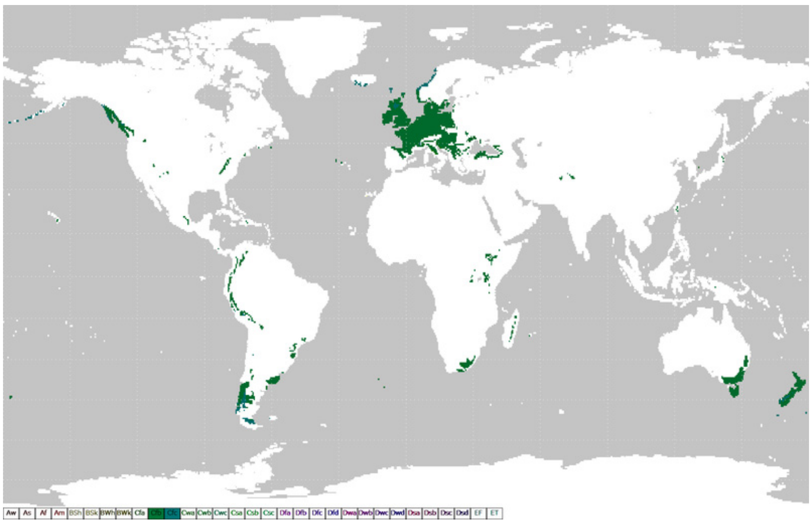


Fig. 4.47 Temperate maritime climate

The architectural practice and the local stylistic context found many ways of addressing cladding. Materials range from high performance glass to cor-ten and wood siding. No material can be singled out as being specific.

Fig. 4.48 Tom Kundig – Delta Shelter, WA., USA, 2005

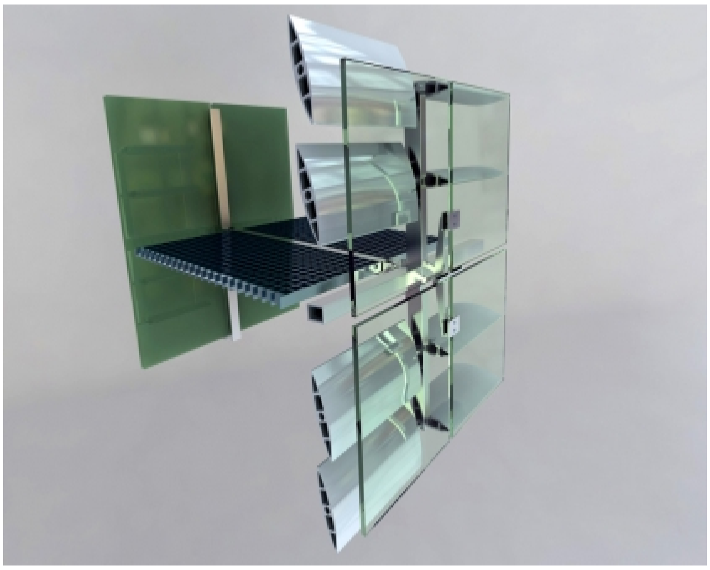


Fig. 4.49 Werner Sobek – glazing detail

Fig. 4.50 Werner Sobek – Sobek House, Stuttgart 2000

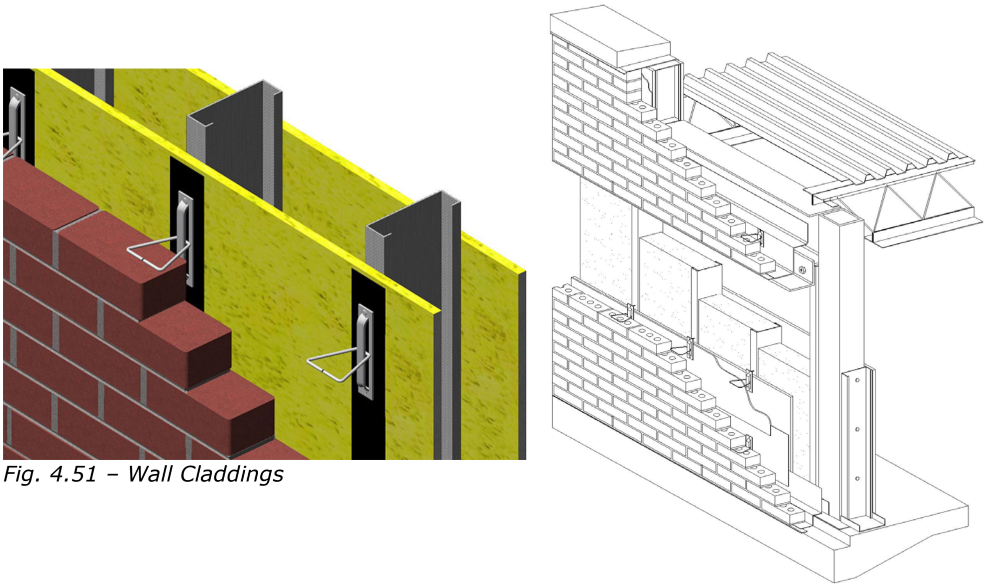


Fig. 4.51 – Wall Claddings

Fig. 4.52 The Dorlonco system

Temperate continental climates, experience extreme seasonal temperatures and call for well suited envelope design solutions. During the cold season, the specific design requirements for buildings in the northern countries are sufficient or exceed the actual needs.

During the hot season, ventilation requirements have to be addressed with the effect of influencing architectural composition. More than in Western Europe, the cladding materials are usually stucco (thermo system) and sometimes wood cladding.

Fig. 4.53 – Thermal insulation

Fig. 4.54 M. Mutiu, P. House, Timisoara, 2010 – front view

The specific conditions for hot and humid climates demand specific solutions which enhance natural ventilation and shading.

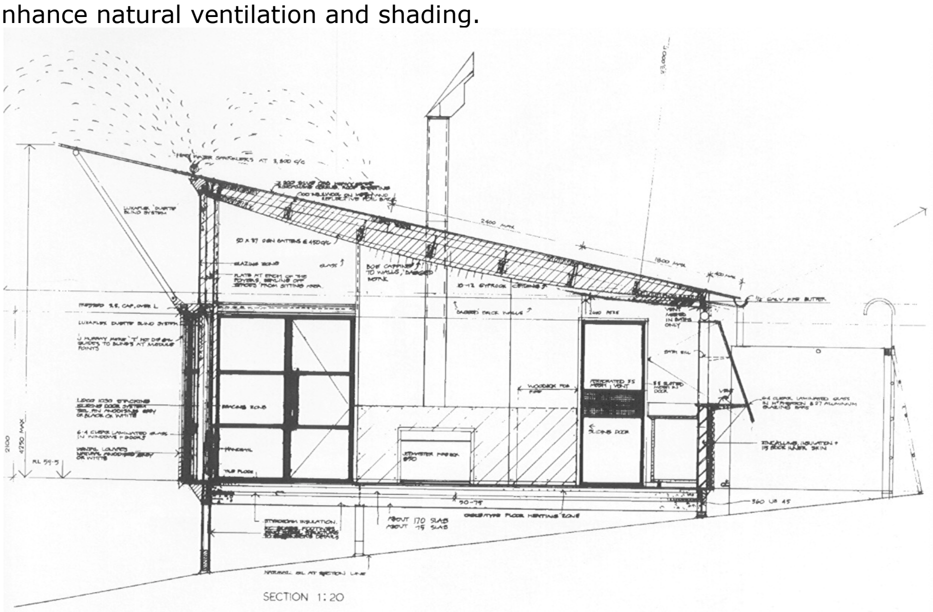


Fig. 4.55 Glenn Murcutt - Simpson Lee House, New South Wales, Australia, 1994 –cross section

As far the cladding materials, the choice varies from corrugated steel, as in the work of noted Australian architect Glen Murcutt, to stucco or compressed earth.

One of the noted architects specializing in the design of steel houses for the Californian desert, Donald A. Wexler, was an early advocate of the use of steel as a very suitable building material for this region of the US, subject to an extreme climate.

"Steel, concrete and glass are the ideal materials to build in the desert, as they are not organic and they do not deteriorate under the effect of extreme temperatures"

Fig. 4.56 Jean Prouve –Maison Tropicale, Brazzavile, Congo, 1949 Steel Prefabricated Frames

Fig. 4.57 Glenn Murcutt Simpson lee House, New South Wales, Australia, 1994

Fig. 4.58 – Corrugated steel sheet

Architectural Solutions by Market Addressability

The architectural solutions for steel framed houses presented above, are grouped taking into account two major parameters, i.e., the structural system and the envelope.

A very important parameter though are economics. Therefore, we will present at the end of this chapter some examples which illustrate the wide array of solutions steel framing can support, given the appropriate construction budget.

Innovation in residential steel frame design often comes from houses which are nothing but average.

The Glass Pavilion designed and built by developer and self taught architect Steve Hermann, demonstrates what an extravagant budget can deliver on a 1300 m^2 house, located in a region with very moderate climate.

Fig. 4.59 Steve Hermann –Glass Pavilion, Montecito, Ca., USA

The Glass Pavilion is significant yet from another point of view, which is the complete integration of architectural and interior design, to which we are referring in chapter 5.

It has to be emphasised though, that our preoccupation in this thesis lies with the average sized house, 150-300sqm.

An affordable, mainstream example is this Parisian house by architect George Maurios, which in a way is a house manifesto, given the total exposure of the steel structure and the steel cladding.

Fig. 4.60 George Maurios – Maurios House

Another example of steel architecture, of neo-vernacular expression, well suited for a suburban or rural application, is this house by Austrian architect Bernardo Bader, with wood shingles cladding.

Fig. 4.61 Bernardo Bader – Private House, Schwarzach, Austria, 2006

In order to conclude our presentation of mainstream solutions for steel framed houses we will present 3 solutions proposed within the Arcelor Mittal Affordable House Project 2010.

All the examples have about 120 m^2 of liveable space and they are using steel framing.

Fig. 4.62 Rzeszow University of Technology – Poland
Affordable House Project-2010

The Polish entry to the 2010 Affordable House Project combines a neo-vernacular architectural form like the pitched roof with modern cladding materials.

Fig. 4.63 Wood Shingles Cladding- Mutiu, Gherman, arch, Affordable House Project-2010

The same architectural expression, leaning on the neo-vernacular was proposed by our design team within the "Affordable House" project of Arcelor-Mittal, for a 2 storey house of 120 m^2.

Fig. 4.64 University of Coimbra-Portugal– Affordable House Project-2010

The Portuguese participation to the 2010 Affordable House Project proposed a modern plastic expression, very well suited to the region's climate and traditional architectural form.

The riddle of Style

This thesis does not intend to investigate the relationship
between architectural styles and the gradual acceptance by architects, of steel as a new and revolutionary , building material. Nevertheless, some critical observations regarding architectural expression in its relationship with steel framing are necessary in order to complete this overview of architectural solutions for steel framed houses. The use of steel gave architects a lot of freedom of expression, both in layouts and form.

Fig. 4.65 Mies van der Rohe – Farnsworth House, 1951

.

During the1930', starting with the iconic examples of the modern movement, as the holyday pavilion of Mies van der Rohe, all kinds of architectural expressions were experimented.

Probably, the dilemma faced by modern architecture is best expressed by Arthur Drexler in his essay "Engineer's Architecture: Truth and its Consequences":

"If, in the pursuit of the absolute, we wish to exalt the act of building while devaluing its contingent forms, as the bewildering freedom contingency implies, then we will seek to purify techniques until they become the visible record of the act of building and nothing more. Proceeding by reduction, modern architecture is uniquely the Engineering Style. It is the art of the real-real structure-and its enemy has been the fictive body with which all previous styles have declared their values and expectations. Engineering was the purification of architecture necessary for the final solution-the solution to the problem of existence in historical time. *Objectivity* begins by sorting out conflicting demands, but its aim is to end the conflict by producing the definitive building. Should that happen not styles merely but the historical process must come to an end."

Fig. 4.66 Daniel Liebeskind – Liebeskind Villa, Germany,

Indeed, by 1987, Phillip Johnson, 38 years after the completion of his famous Glass House, was quoted as saying: "Between 1949 and the late 1970's, I decided that modernism, with it's rigid rules for simple functional forms, was totally boring and lacking in richness. I had been experiencing the past in various ways and breaking the rules in the other building I put up near the Glass House. During that time I had decided that I wanted to be able to explore the past without being bound by rules."

Post-modernism did not care to much about the use of steel, as the "fictive body" of the building was all important. On the contrary, deconstructivism found in steel the perfect vehicle to make real the most audacious designs, as this 515 m^2 high-tech villa by famous architect Daniel Liebeskind, completed in 2009 in Germany, for a price tag of 2 mil. Euro

In the 70's, experiments with steel frame architecture tried to break from the rectilinear dogma of the International Style, very much in tune with the mood expressed by Phillip Johnson. In the work of noted Canadian architect Arthur Erikson, steel frames are used, in the example below, in order to project a new architectural language, which appears somewhat dated today.

Fig. 4.67 Arthur Erikson – Hugo Eppich House, West Vancouver, Can., 1979

In terms of architectural audacity, architects can choose today from a great variety of building materials and techniques. Therefore, a house manifesto can look like the famous house by Sarah Wigglesworth which combines steel framing and straw-bale walls, or as the futuristic steel house by Meixner Schluter Wendt.

Fig. 4.68 Sarah Wigglesworth – The Straw-Bale House

Fig. 4.69 Meixner Schluter Wendt – House F., Kronsberg, Ger.

In house F, the German architect Meixner Schluter Wendt demonstrates how local building regulations can be respected in an innovative approach. In this example, the building's shape is determined by local rules which insist on having pitched roofs, which is realized here in a very futuristic expression.

Fig. 4.70 Arts et Metiers Paris Tech - Napevomo House

Another serious consideration when we speak of architectural expression is the need to find a way of incorporating the new technological components typical to low energy houses as solar and photovoltaic panels. In the example presented, the experimental Napevomo House by the interdisciplinary team of Arts et Metiers Paris Tech, won in 2010 the first prize of the solar decathlon Europe. While the energy efficiency of the proposal is beyond doubt, one can wonder how suitable is such an architectural design for the typical subdivision, in other words, what will be its level of acceptance by the public.

Probably, the return of residential architecture or at least of some of its more remarkable exponents to a more "classical" or balanced approach, which prompted architectural critics to label it "classical modernism", shows that architectural expression is not lessened when it tries to blend simplicity, clarity and the search of proportions.

In this sense, emblematic stays the work of Werner Sobeck, whose architectural work, while striving to incorporate the most advanced eco-technology, does not loose its elegant expression.

Fig. 4.71 Werner Sobek – Sobek House

4.4. Conclusions to Chapter 4

The use of steel frame structures in residential design brings to the process layout flexibility and greater freedom of expression.

The Evolution of Iron and Steel Framed Houses presented in this chapter shows that building techniques using this materials were known for some time and that their gradual acceptance by the residential sector was rather slow and associated with the great names of modern architecture.

The use of steel frames in residential projects which were trying to address the social problems of the day goes back almost 100 years.

The architectural solutions for steel framed houses presented in this chapter are grouped in a couple of categories, ranging from structural system and envelope, to market addressability and architectural style.

We can conclude that the use of steel frames in residential applications evolved in parallel with the evolution of layouts and the search for architectural expression, for whom, steel provides new and rational constructive solutions.

5. Integrated Design for Steel Framed Houses

5.1. Introduction

Sustainable design and construction strategies are of great importance nowadays. One may say that sustainability was already a driving force in the past, exhibiting its validity through the different forms and techniques used. Therefore, from Vitruvius till today, problems and precautions in design and construction did not change fundamentally, although many developments have been seen in materials and technology. Moreover, these developments may have had some negative effects. That is the reason why the building process should be discussed in a holistic way. In other words, climatically responsive design, selection of materials and building techniques and HVAC solutions must be evaluated together and the final product should perform well during its whole service life. Reducing energy consumption, using natural resources and providing comfortable, healthier and sustainable living spaces are the aims of a climatically responsive sustainable building design.

5.2. Architectural versus Structural Design

Fundamental definitions of the architect's roles and ambitions can be found in the work of the Roman engineer and the first architectural educator, Vitruvius. These definitions can be interpreted to include the concepts of sustainability:

- Commodity, usually understood as fitness for use, is broadened to mean effectiveness, in environmental, economic, and programmatic terms.
- Firmness, surpasses structural reliability and incorporates long term environmental sustainability, comfort, and longevity.
- Delight, moves beyond pleasure in aesthetics and embraces deeper meaning.

A significant achievement of the first industrial age was the emergence of building science, particularly the elastic theory of structures. With it, mathematical models could be used to predict structural performance with considerable accuracy, provided there was adequate quality control of the materials used. Although some elements of the elastic theory, such as the Swiss mathematician Leonhard Euler's theory of column buckling (1757), were worked out earlier, the real development began with the English scientist Thomas Young's modern definition of the modulus of elasticity in 1807. Louis Navier published the elastic theory of beams in 1826, and three methods of analyzing forces in trusses were devised by Squire Whipple, A. Ritter, and James Clerk Maxwell between 1847 and 1864. The concept of a statically determinate structure--that is, a structure whose forces could be determined from Newton's laws of motion alone--was set forth by Otto Mohr in 1874, after having been used intuitively for perhaps 40 years. Most 19th-century structures were purposely designed and fabricated with pin joints to be statically determinate; it was not until the 20th century that statically indeterminate structures became readily solvable. The elastic theory formed the basis of structural analysis until World War II, when bomb-damaged buildings were observed to behave in unpredicted ways and the underlying assumptions of the theory were found to require modification.[35]

The coming of the industrial age also marked a major change in the role of the architect. The artist-architects of the Renaissance had the twin patrons of church and state upon whom they could depend for commissions. In the rising industrial democracies the market for large-scale buildings worthy of an architect's attention widened, and the different users asked for a bewildering range of new building types. The response of the architect was to develop the new role of licensed professional on the model of professions such as law and medicine. In addition, with the coming of building science, there was a further division of labour in the design process; structural engineering appeared as a separate discipline specializing in the application of mathematical models in building. One of the first buildings for which the architect and engineer were separate persons was the Granary (1811) in Paris. Societies representing the building design professions were founded, including the Institution of Civil Engineers (1818) and the Royal Institute of British Architects (1834), both in London, and the American Institute of Architects (1857). Official government licensing of architects and engineers, a goal of these societies, was not realized until much later, beginning with the Illinois Architects Act of 1897. Concurrent with the rise of professionalism was the development of government regulation, which took the form of detailed municipal and national building codes specifying both prescriptive and performance requirements for buildings. [35]

5.3. The Integrated Design Approach

One of the most serious obstacles that develop during a design process, having the potential to impact negatively upon the overall performance, come from the sequential way in which we are bound and trained to think.

Ideally, we should be able to grasp the problem in its entirety from the very beginning and to address afterwards in an orderly manner, all the project components. Such mental processes and working methods are used to some degree in the artistic realm, but, for practical reasons cannot be easily applied to construction design. Nevertheless, while *thinking alone* the concept, the architect is doing, in part at least, exactly that. In other words, he the architect has to be *right* from the very beginning. But, as Oscar Wilde, once said

"The imagination imitates. It is the critical spirit that creates ".

The design process is not science in itself, it only uses scientific methods. The concept is in fact a *working hypothesis*, which has to be validated by *Reality.* That means that the concept has to be right, from the beginning.

This is a very tricky question indeed. Given the costs associated with the design process, it is very difficult to start with more that one concept and to simultaneously develop them up to the point where they can be compared.

This method, generally used in graphic design, can be afforded only by large design groups. Today, this is called *holistic design approach.*

The conceptual design is one of the most important step in the design of a cold formed steel construction. In fact, the best design of a light gauge can be achieved when a holistic design approach is applied. Therefore, architectural and conceptual design should be developed in parallel.

This is more easily said than done, because the architectural and structural concepts have to match each other from the start.

It follows that the importance of this first phase is paramount.

In this step, the construction system, the thermal, sound and fire performance that have to be reached and the main general structural concerns have to be defined. As matter of fact, the members that best conform to the physical characteristics of the building can be defined very early in the design process as well as soundproofing, heat and fire resistance can be studied since the beginning of the design in order to reach the best solution with the minimum costs and time.

Once, the conceptual design is defined, and from a structural viewpoint the most relevant actions and the main structural components have been defined, then the structural design can be developed as summarized in the following flow chart.

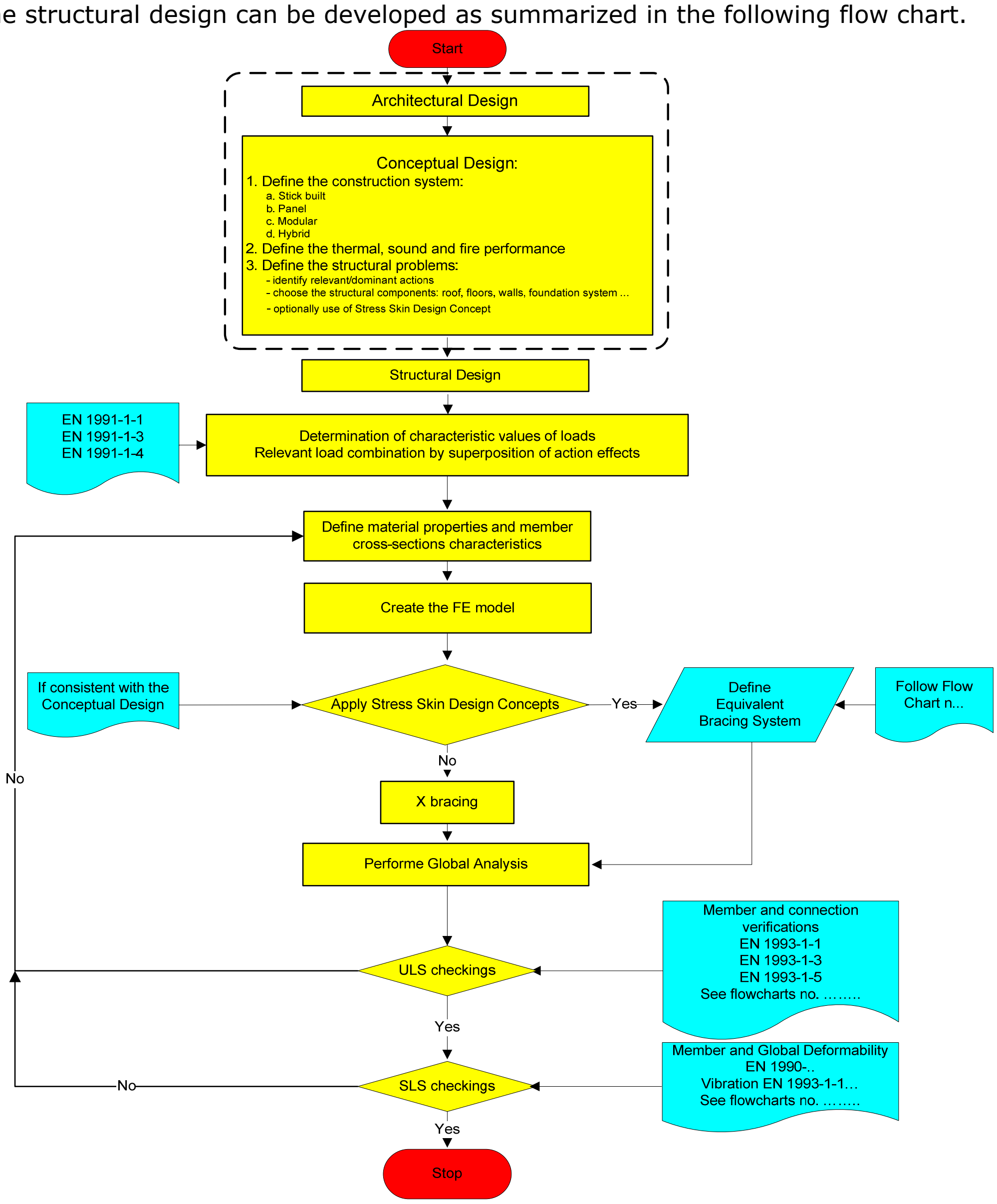


Fig. 5.1. Building Design Flow Chart

In order to understand what the integrated design process (IDP) is, it is useful to first characterize the more conventional design process. The process often begins with the architect and the client agreeing on a design concept, consisting of a general massing scheme, orientation, fenestration and, usually, the general exterior appearance as determined by these characteristics as well as by basic materials. The mechanical and electrical engineers are then asked to implement the design and to suggest appropriate systems. [36]

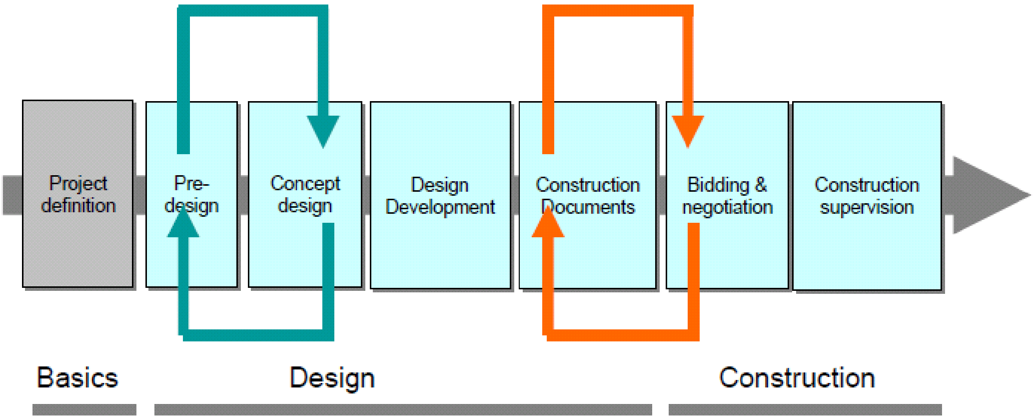


Fig. 5.2. Graphic representation of the conventional design process

Although this is vastly oversimplified, such a process is one that is followed by the large majority of general-purpose design firms, and it generally limits the achievable performance to conventional levels. The traditional design process has a mainly linear structure due to the successive contributions of the members of the design team. There is a limited possibility of optimization during the traditional process, while optimization in the later stages of the process is often troublesome or even impossible. For example, little advantage may be taken of passive solar potential, there may be excessive exposure to high solar gain during the summer, and poor daylighting and discomfort for the occupants. [36]

All these potential outcomes reflect a design process that appears to be quick and simple, but actual results are often high operating costs and an interior environment that is sub-standard; and these factors in turn may greatly reduce the long-term rental or asset value of a property. Since the conventional design process usually does not involve computer simulations of predicted energy performance, the resulting poor performance and high operating costs will most often come as a surprise to the owners, operators or users. [36]

Integrated design is distinguished from conventional design by its use of a highly collaborative, multidisciplinary project team. The team works as a collective to understand and develop all aspects of the design. The design can then emerge organically, with the full benefit of each expert's input—a structural engineer can contribute to the elegance and efficiency of the structure, a mechanical engineer can inform choices that enhance energy efficiency and comfort, a landscape architect and civil engineer can optimize the layout and orientation, an interior designer can improve the indoor spaces, a contractor can enhance the constructability of the resulting design, and a cost estimator can manage the budget. Depending on the size and complexity of the project, the owner, prospective occupants, facility managers, and a wide range of specialty consultants may be involved as well. While each expert plays an essential role, in effective integrated design exercises the best ideas often emerge when participants cross the usual boundaries, because their views are not as limited by familiarity with the way things are usually done. [37]

The IDP process contains no elements that are radically new, but integrates well-proven approaches into a systematic total process. When carried out in a spirit of cooperation among key actors, this results in a design that is highly efficient with minimal, and sometimes zero, incremental capital costs, along with reduced long-term operating and maintenance costs. The benefits of the IDP process are not limited to the improvement of environmental performance. Experience shows that the open inter-disciplinary discussion and synergistic approach will often lead to improvements in the functional program, in the selection of structural systems and in architectural expression. [37]

The IDP process is based on the well-proven observation that changes and improvements in any design process are relatively easy to make at the beginning of the process, but become increasingly difficult and disruptive as the process unfolds. Although this may seem obvious, it is a fact that most clients and designers have not followed up on the implications. As well, the existence of a defined roadmap gives credence and form to the process, making it easier to promote and implement.

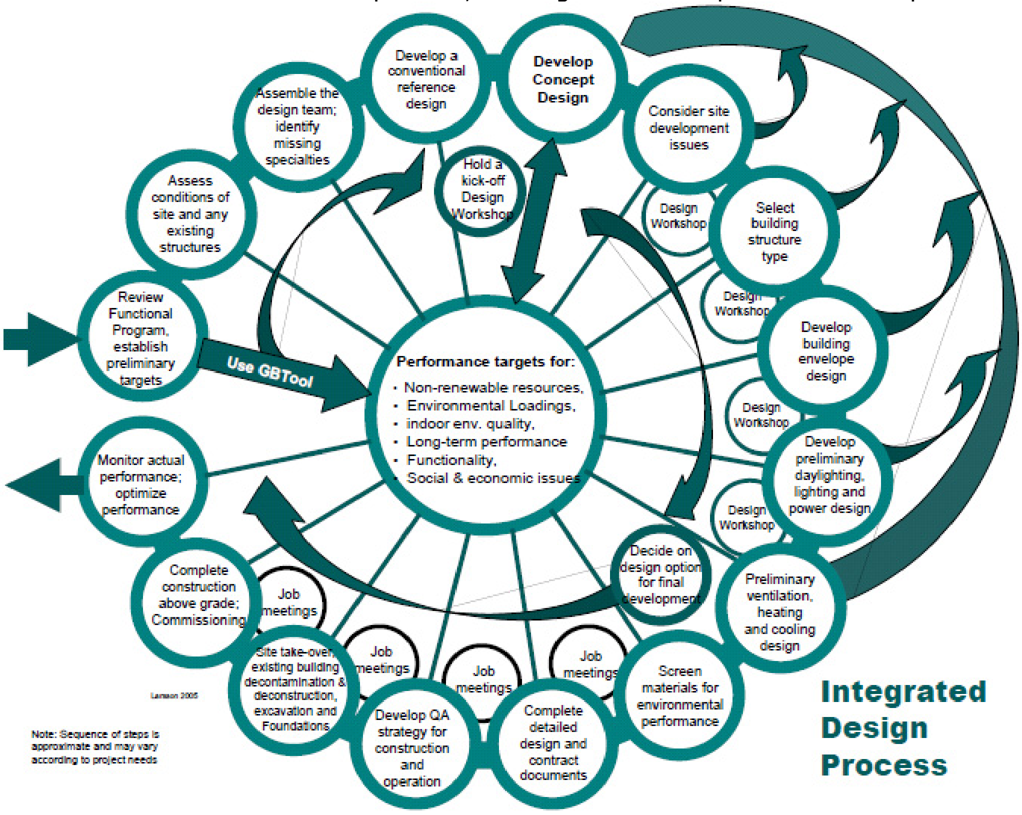


Fig. 5.3. Graphic representation of the IDP Process

Typical IDP elements include the following:

- inter-disciplinary work between architects, engineers, costing specialists, operations people and other relevant actors right from the beginning of the design process;

- discussion of the relative importance of various performance issues and the establishment of a consensus on this matter between client and designers;
- budget restrictions applied at the whole-building level, with no strict separation of budgets for individual building systems, such as HVAC or the building structure. This reflects the experience that extra expenditures for one system, e.g. for sun shading devices, may reduce costs in another systems, e,g., capital and operating costs for a cooling system;
- the addition of a specialist in the field of energy engineering and energy simulation;
- testing of various design assumptions through the use of energy simulations throughout the process, to provide relatively objective information on this key aspect of performance;
- the addition of subject specialists (e.g. for daylighting, thermal storage, comfort, materials selection etc.) for short consultations with the design team;
- clear articulation of performance targets and strategies, to be updated throughout the process by the design team; and
- in some cases, a Design Facilitator is added to the team to raise performance issues throughout the process and ensure specialist inputs as required. [36]

Based on experience in Europe and North America, an IDP is especially characterized by a series of design loops per stage of the design process, separated by transitions with decisions about milestones. In each of the design loops the design team members relevant for that stage participate in the process.

The design process itself emphasizes the following broad sequence.

1. Establish performance targets for a broad range of parameters, and develop preliminary strategies to achieve these targets. This sounds obvious, but in the context of an integrated design team approach it can bring engineering skills and perspectives to bear at the concept design stage, thereby helping the owner and architect to avoid committing to a sub-optimal design solution.

2. Minimize heating and cooling loads and maximize daylighting potential through orientation, building configuration, an efficient building envelope and careful consideration of the amount, type and location of fenestration.

3. Meet heating and cooling loads through the maximum use of solar and other renewable technologies and the use of efficient HVAC systems, while maintaining performance targets for indoor air quality, thermal comfort, illumination levels and quality, and noise control.

4. Iterate the process to produce at least two, and preferably three, concept design alternatives, using energy simulations as a test of progress, and then select the most promising of these for further development. [36]

Advantages of the IDP:

- IDP is a method to intervene in the design stage to ensure that all issues that can be foreseen to have a significant impact on sustainable performance are discussed, understood and dealt with at the beginning of the design process;
- IDP helps the client and architect to avoid a sub-optimal design solution;
- Integrated design process results in an integrated systems approach, and that can have many positive results;
- It enables the achievement of high levels of building performance through integrated systems design. [36]

Successful integrated design depends on two key factors: thinking outside the box and working as a team from the beginning. Creating an effective collaborative process requires clear intention and skill, especially for large, complicated projects with numerous consultants and participating stakeholders. And every participant must be open-minded about potential design solutions and willing to take some risks. [36]

Integrated design is key to creating cost-effective green buildings, but it is more than that. It encourages us to expand our thinking beyond the immediate design problem, as it is presented, and think about what we are doing and why. As such, it is reinforcing the connections between green building and social issues.

5.4. Structural Design and Building Solutions

Builders in the commercial and industrial sector have long recognized the many benefits of steel framing, such as consistent quality, precision measurements, light weight and infinitely variable lengths. As production techniques have been refined and new technologies have arisen, steel framing is securing increasing use in the domestic market. [38]

Steel structures are likely to be subjected to various types of loads and deformations arising from service requirements that may range from the routine to the extreme or accidental. All relevant loads should be considered separately and in such realistic combinations as to give the most critical effects on the elements being designed and the structure as a whole. The magnitude and frequency of fluctuating loads should also be considered.

The self-weight of construction works should be classified as a permanent fixed action. Where this self-weight can vary in time, it should be taken into account by the upper and lower characteristic values. The total self-weight of structural and non-structural members should be taken into account in combinations of actions as a single action.

Imposed loads shall be classified as variable free actions, unless otherwise specified. For areas which are intended to be subjected to different categories of loadings the design shall consider the most critical load case. In design situations when imposed loads act simultaneously with other variable actions (e.g. actions induced by wind, snow), the total imposed loads considered in the load case shall be considered as a single action.

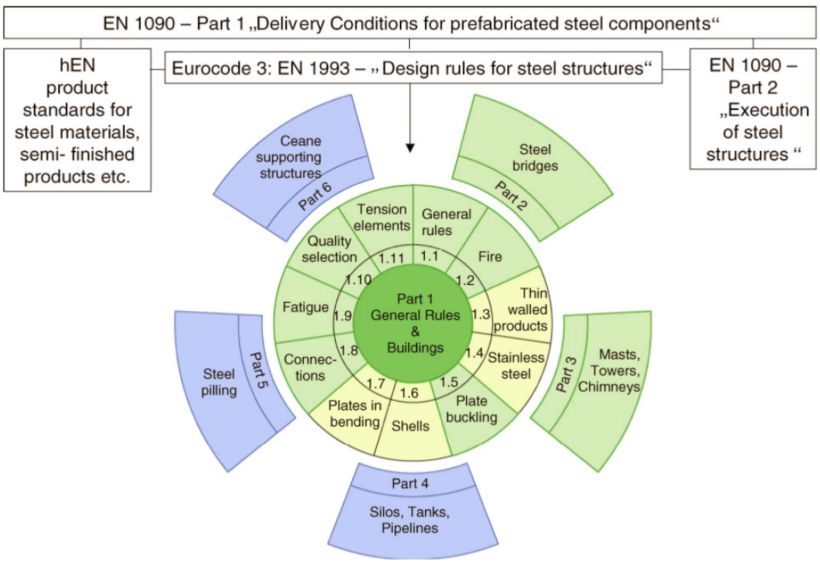


Fig. 5.4. Standard system for steel structures (Sedlacek & Müller, 2006)

The Romanian codes are aligned to relevant Eurocodes:

- Dead loads (architectural details and SREN1991-1-1);
- Snow loads (SREN1991-1-3 and CR1-1-3-2005);
- Wind loads (SREN1991-1-4 and NP-082-04);
- Imposed loads (SREN1991-1-1);
- Seismic loads (P100-1/2006);
- Combinations of actions (SREN1990:2002).

Snow Load

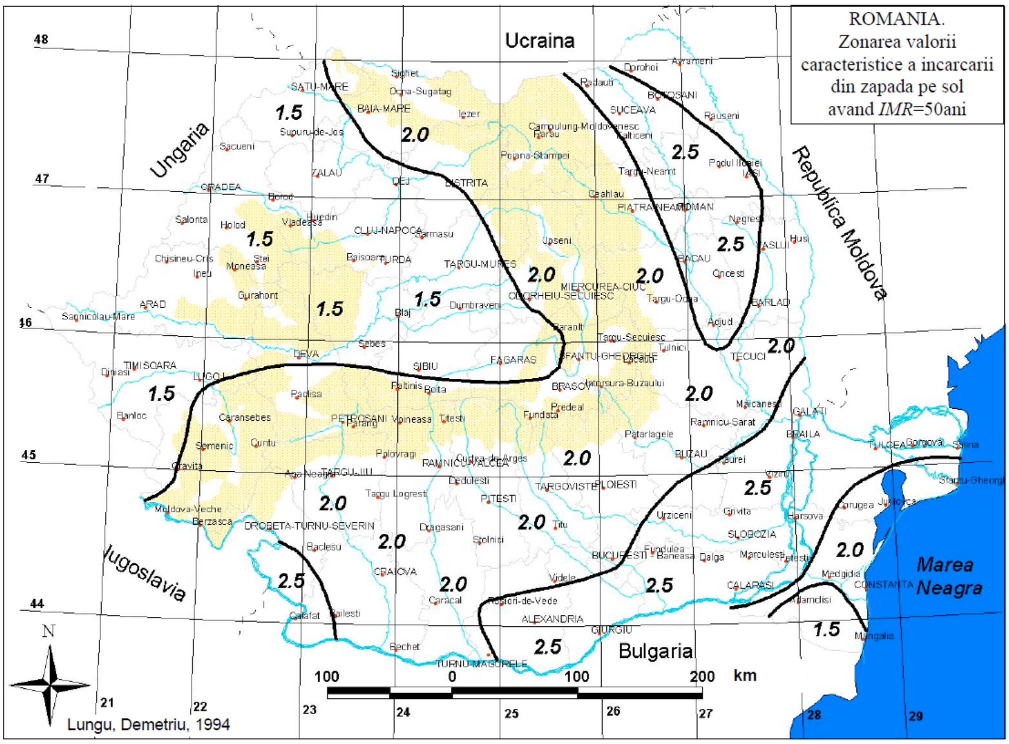


Fig. 5.5. Romanian snow load coefficients

$$s_k = \mu_i * C_e * C_t * s_{0,k}$$

μ_i – the shape coefficient for the snow load on the roof
C_e – the exposure coefficient for the building's location
C_t – thermal coefficient
$s_{0,k}$ – the characteristic value of the snow load on the ground [kN\mp]

Wind Load

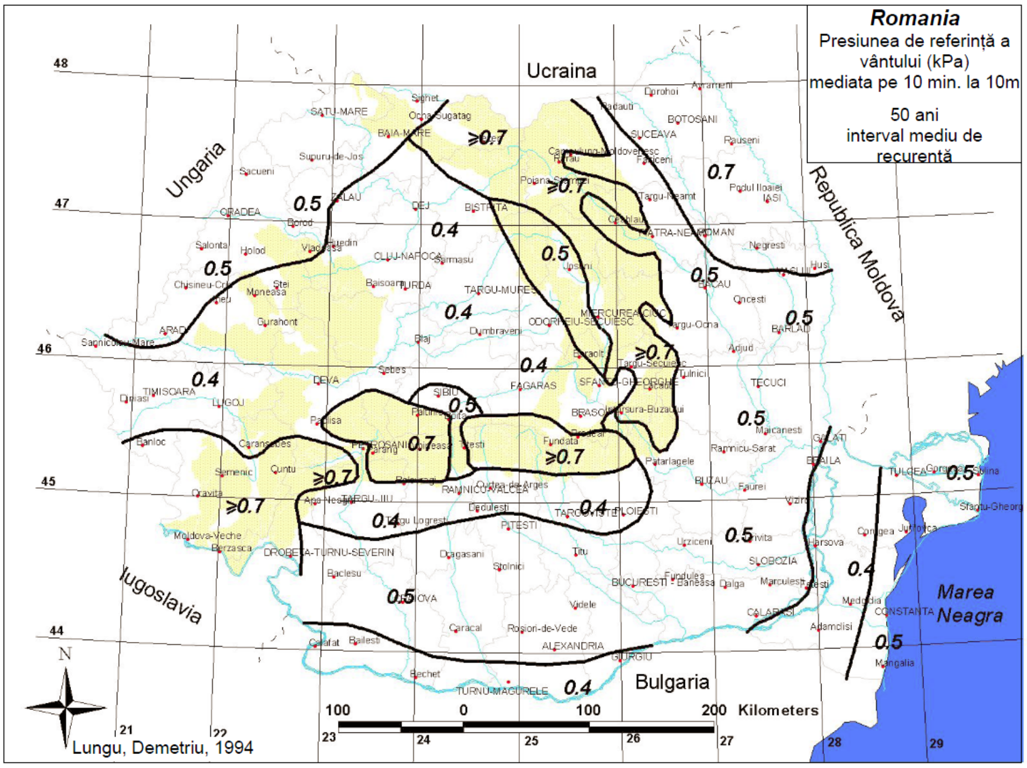


Fig. 5.6. Romanian wind load coefficients

$$w_z = q_{ref} * c_{e(z)} * c_p$$

q_{ref} – the reference wind pressure
$c_{e(z)}$ – the exposure factor at the height z over the field
c_p – the external pressure coefficient

Seismic Action [45]

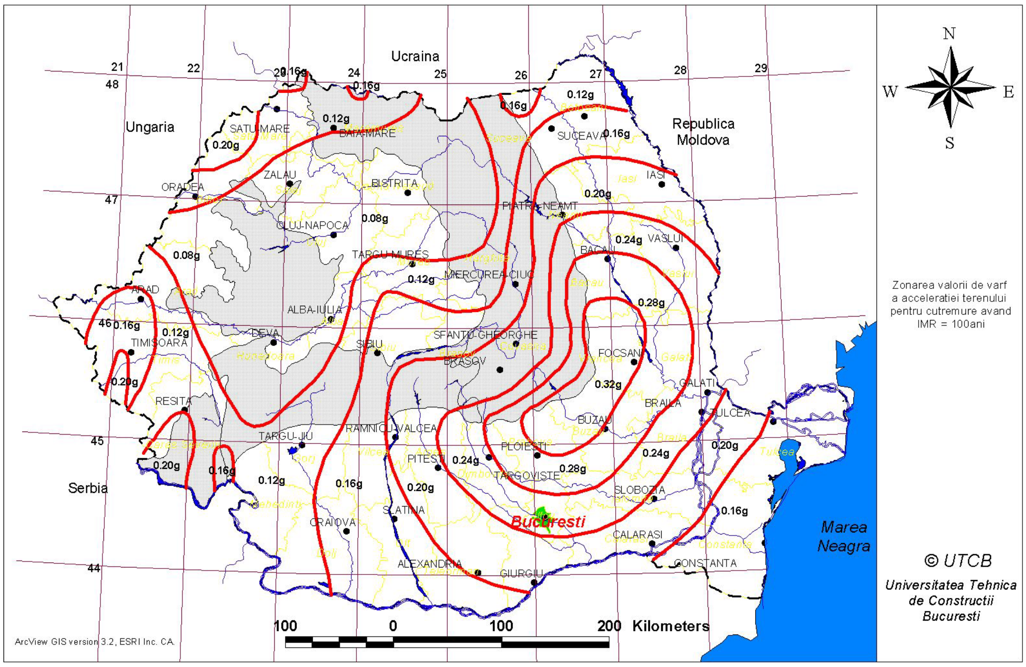
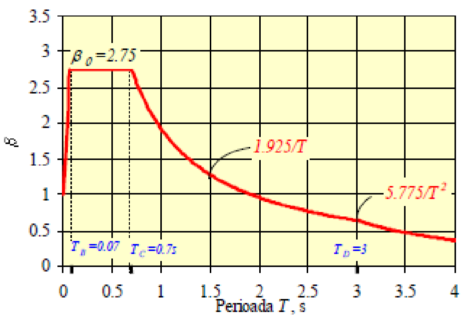


Fig. 5.7. Romanian seismic map



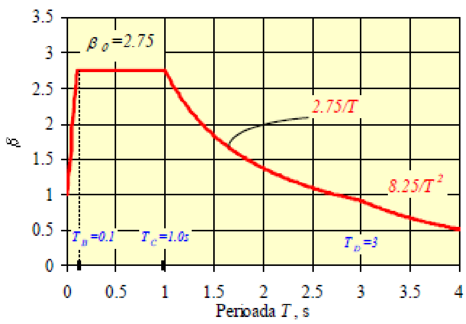
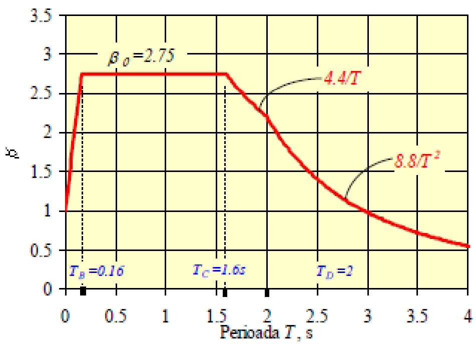


Fig. 5.8. Normalized elastic response spectra for accelerations for the horizontal components of the ground movement, in the zones which are characterized by the control periods (corner periods): TC = 0.7, TC = 1.0 and TC = 1.6s



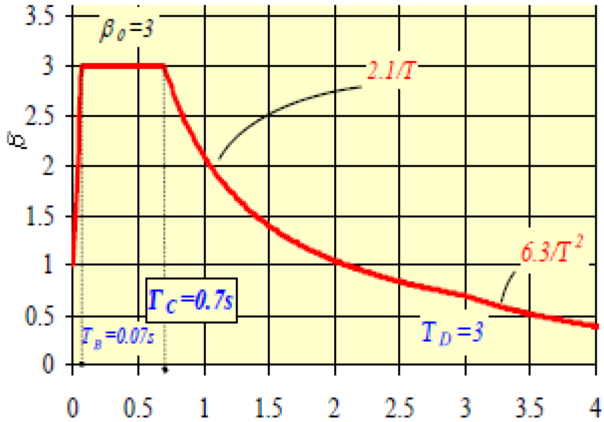


Fig. 5.9. Crustal sources in Banat: normalized elastic response spectrum for accelerations for the horizontal components of the ground movement, for the zones where the seismic hazard is characterized by ag = 0.20g and ag = 0.16g.

(1) In case of seismic action for the design of buildings, the Romanian territory is divided in seismic hazard zones. The seismic hazard level in every zone is considered, in a simplified way, to be constant. It is recommended, for important urban centers and for buildings of particular importance, to resort to the local assessment of the seismic hazard, on the basis of the instrumental seismic data and of the specific studies regarding the site under consideration. The seismic hazard level indicated in the present code is a minimum design level.

(2) The seismic design hazard is described by means of the value of the peak horizontal ground acceleration ag, determined for the mean recurrence (MRI) corresponding to the ultimate limit state, a value which is hereinafter referred to as "the design ground acceleration".

(3) The design ground acceleration, for every seismic hazard zone, corresponds to a reference mean recurrence interval of 100 years. The zoning of the design ground acceleration ag in Romania, for seismic events having the mean recurrence interval (of the magnitude) MRI = 100 years, is indicated in the Figure 5.6 and is used for the design of buildings at the ultimate limit state.

(4) The seismic movement in a point on the surface of the ground is described by the elastic response spectrum for absolute accelerations.

(5) The horizontal seismic action on buildings is described by two orthogonal components considered to be independent from one another; the design elastic response spectrum for absolute accelerations is considered to be the same for the two components.

(6) The normalized elastic response spectra for accelerations are obtained from the elastic response spectra for accelerations, by dividing the spectral ordinates by the value of the peak ground acceleration ag.

(7) The local ground conditions are described by the values of the control period (corner period) TC of the response spectrum for the zone of the site under consideration. These values characterize in a synthetic way the frequency content of the seismic movements. The control period (corner period) TC of the response spectrum represents the border between the zone (level) of maximum values in the spectrum for absolute accelerations and the zone (level) of maximum values in the spectrum for relative velocities.

(8) The normalized forms of the elastic response spectra for the horizontal components of the ground acceleration β(T), for the viscous damping ratio of ξ =0.05 and on the basis of the control periods (corner periods) TB, TC and TD, are the following:

$$0 \le T \le T_B: \quad \beta(T) = 1 + \frac{(\beta_0 - 1)}{T_B} T$$

$$T_B < T \le T_C: \quad \beta(T) = \beta_0$$

$$T_C < T \le T_D: \quad \beta(T) = \beta_0 \frac{T_C}{T}$$

$$T > T_D: \quad \beta(T) = \beta_0 \frac{T_C T_D}{T^2}$$

β(T) the normalized elastic response spectrum;

β_0 the factor of maximum dynamic amplification of the horizontal ground acceleration by the structure;

T vibration period of a linear single-degree-of-freedom system.

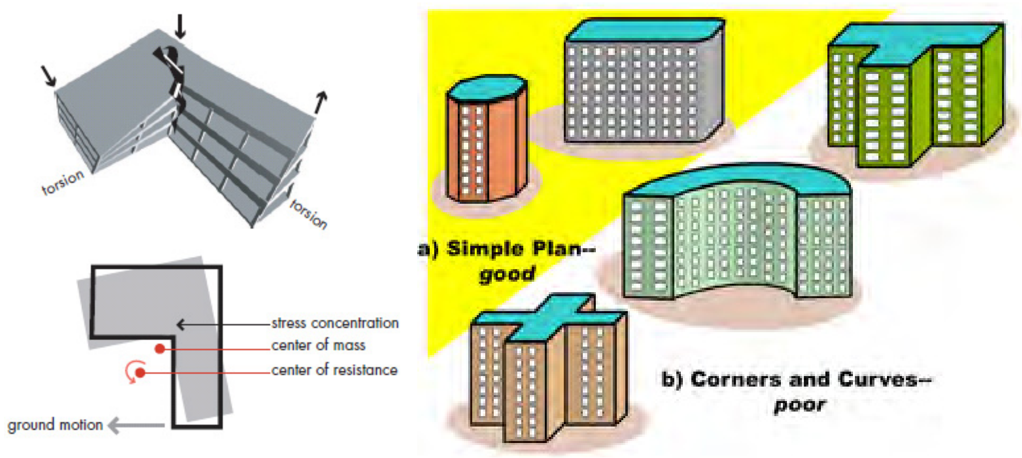
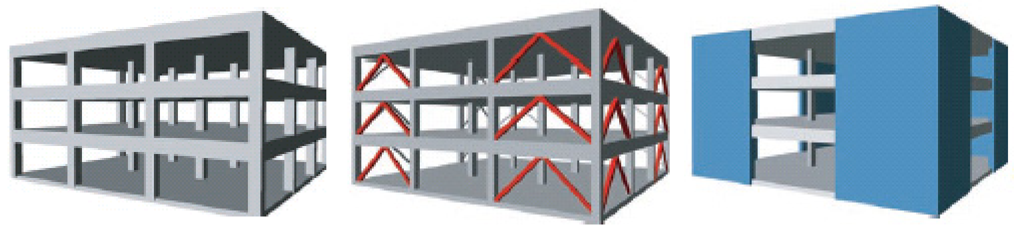


Fig. 5.10. Influence of building shape: a) Buildings with simple shapes permit the shaking induced inertia forces to flow directly to the foundation and hence perform well in earthquakes; b) buildings with irregular shapes force the inertia forces to bend at eachre-entrant corner, which results in damage at these corners and hence poor earthquake performance of the building as a whole (source: Murty 2005).



moment resisting frame *braced frame* *shear walls*

Fig. 5.11. The three basic vertical seismic system alternatives.

Romania is characterized by a moderate to high seismic activity territory, o country with hot summers and cold winters with moderate to heavy snow, i.e. Romania covers a wide range of climatic, geotechnical and seismic conditions.

Natural Conditions	Snow Load [KN/m²]	Wind Pressure [KPa]	Frost Depth [m]	Ground Acceleration
Interval Values	**1.5 – 2.5**	**0.4 – 0.7**	**0.6 – 1.1**	**0.08g – 0.32g**

Tab. 5.1 Romanian Natural Loads

Load Combinations

Ultimate Limit State
Fundamental Loads

$$1{,}35\sum_{j=1}^{n} G_{k,j} + 1{,}5\, Q_{k,1} + \sum_{i=2}^{m} 1{,}5\, \psi_{0,i}\, Q_{k,i}$$

$G_{k,j}$ – the effect of the dead load on the structure
$Q_{k,I}$ – the effect of the predominant variable load on the structure
$Q_{k,i}$ – the effect of the variable load "i" on the structure
$\Psi_{0,i}$ – coefficient for the simultaneity of effects on the structure

Exceptional Loads

$$\sum_{j=1}^{n} G_{k,j} + \gamma_I A_{Ek} + \sum_{i=1}^{m} \psi_{2,i}\, Q_{k,i}$$

G_k – dead load
A_{Ek} – seismical load
γ_k – coefficient for the importance of building
$Q_{k,i}$ – the effect of the variable load "i" on the structure
$\Psi_{2,i}$ - coefficient for determining the variable load

Serviceability Limit State

Fundamental Loads

$$\sum_{j=1}^{n} G_{k,j} + \psi_{1,1} Q_{k,1} + \sum_{i=2}^{m} \psi_{2,i} Q_{k,i}$$

Exceptional Loads

$$\sum_{j=1}^{n} G_{k,j} + 0{,}6\,\gamma_I A_{Ek} + \sum_{i=1}^{m} \psi_{2,i} Q_{k,i}$$

Any design process involves a number of assumptions. The loads to which a structure will be subjected must be estimated, sizes of members to check must be chosen and design criteria must be selected. All engineering design criteria have a common goal: that of ensuring a safe structure and ensuring the functionality of the structure.

To satisfy the ultimate limit state, the structure must not collapse when subjected to the peak design load for which it was designed. A structure is deemed to satisfy the ultimate limit state criteria if all factored bending, shear and tensile or compressive stresses are below the factored resistance calculated for the section under consideration. The limit state criteria can also be set in terms of stress rather than load. Thus the structural element being analysed (e.g. a beam or a column or other load bearing element, such as walls) is shown to be safe when the factored "Magnified" loads are less than their factored "Reduced" resistance.

To satisfy the serviceability limit state criteria, a structure must remain functional for its intended use subject to routine (read: everyday) loading, and as such the structure must not cause occupant discomfort under routine conditions. A structure is deemed to satisfy the serviceability limit state when the constituent elements do not deflect by more than certain limits laid down in the building codes, the floors fall within predetermined vibration criteria, in addition to other possible requirements as required by the applicable building code.

A structure where the serviceability requirements are not met, e.g. the beams deflect by more than the SLS limit, will not necessarily fail structurally. The purpose of SLS requirements is to ensure that people in the structure are not unnerved by large deflections of the floor, vibration caused by walking, sickened by excessive swaying of the building during high winds, or by a bridge swaying from side to side and to keep beam deflections low enough to ensure that brittle finishes on the ceiling above do not crack, affecting the appearance and longevity of the structure.

Structural design for Light Gauge Steel Framed Houses

Light Gauge Steel Framing for housing (LGSF) is a collective concept for a construction system that contains primarily light gauge steel profiles, gypsum, and mineral wool. Steel studs have been used in interior walls and curtain walls for more than 30 and 10 years, respectively, but it was not until competitive light gauge steel floor structures were developed that the entire construction system with structural steel studs became established on the market. This technology is popular and accounts for an important and increasing market share in US, Japan, Australia and Europe.

Use of cold-formed steel framing in the residential market has increased over the past several years. Its price stability, consistent quality, similarity to conventional framing, success in the commercial market and resistance to fire, rot, and termites, have attracted the attention of many builders and designers.

Burstrand presents reasons for choosing light gauge steel framing from an environmental point of view:

- Light Gauge Steel Framing is a dry construction system without organic materials. Dry construction significantly reduces the risks of moisture problems and sick building syndrome.
- Steel, gypsum, and mineral wool are closed cycle materials.
- Every material used in Light Gauge Steel Framing (steel, gypsum, and mineral wool) can be recycled to 100%.
- It is possible to disassemble the building components for re-use.
- Light Gauge Steel Framing means less energy consumption during production than equivalent housing with a framework of concrete poured on-site.
- Light Gauge Steel Framing only uses about a fourth of the amount of raw material used for equivalent homes in concrete.
- Less waste means a cleaner work site and a low dead weight of building components ensures a good working environment.
- Low dead weight leads to reduced transport needs.

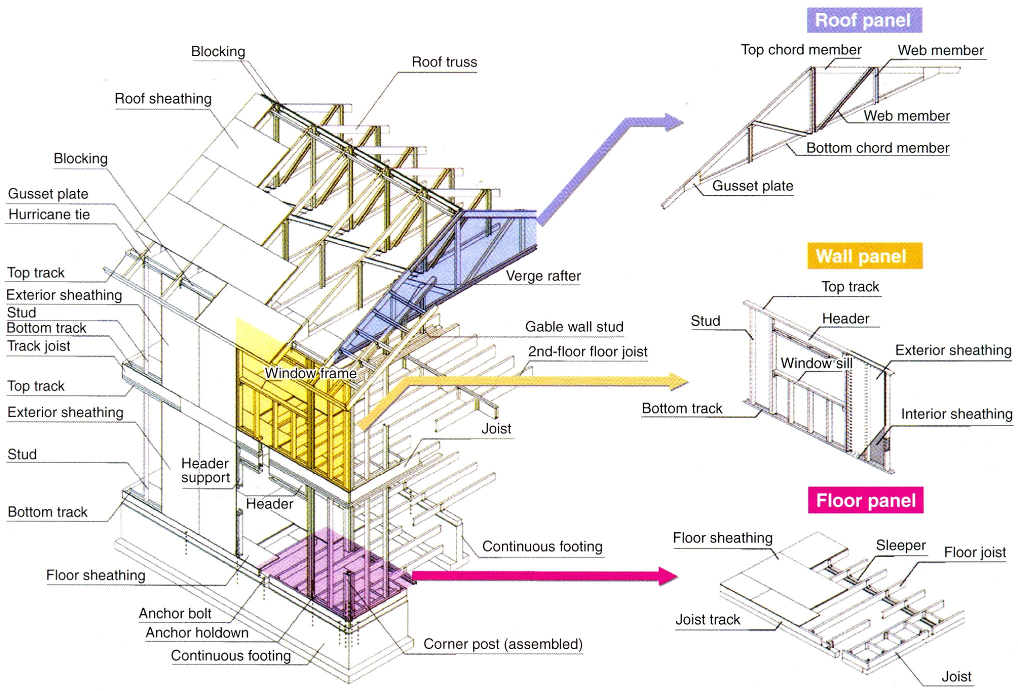


Fig. 5.12. Structures of Steel-framed House

The properties of the steel do not change during the service life of the building. Buildings with a steel frame have a very long life. Rust proofing in the form of modern paints, hot dip galvanising, or a dry or dehumidified climate prevents the steel from rusting. Thin steel profiles are hot dip galvanised with 275 gram of zinc per square meter and from a corrosion perspective the service life is at least 100 years.

As on open system, the Light Gauge Steel Framing construction technique can be used separately or together, for example:

- Structural light gauge steel framing, with light gauge floors in apartment dwellings.
- Structural skeleton framework with light gauge floor structures, interior and exterior walls.
- Interior walls only in multi-unit housing.
- Curtain walls only in homes, office buildings, schools, etc.

Light Gauge Steel Framing can be applied to multiunit housing and single-family homes. With its low weight of around 150 kg/m^2 of floor surface, it is very suitable for additions to existing buildings, or where foundation conditions are poor.

In order to be able to reduce construction costs, construction time must be reduced. Through industrialised housing construction, productivity is increased in all stages. Residential buildings, despite their size and complexity, are very good products for industrial production. Steel constructions, by their nature, are pre-fabricated to some degree and, in particular, three levels of pre-fabrication have been developed for cold formed steel housing: stick-built, panelised and modular constructions. [28]

Stick-built constructions are obtained by assembling on site a modest number of members (studs, joists and rafters) and sheathing panels, which are fastened together by screws, nails or bolts. All the elements are realised in the factory under a controlled environment and transported into the site, where the construction is built up without heavy lifting equipment. This gives rise to the use of a minimum volume of raw material and a reduction of energy to transport and build up the house. Dry constructions assure less disruption and noise on site as well as minimum site waste. These CFS houses, besides being made of light and standard elements, can be adaptable and flexible to different site conditions and to changing lifetime requirements. Moreover, high structural performance and good acoustic and thermal behaviour can be achieved by careful design. This system increases the flexibility offered by steel framing, enabling last minute changes and adjustments to the design. The stick-built system is particularly suitable for homes with unusual dimensions and design features. [39]

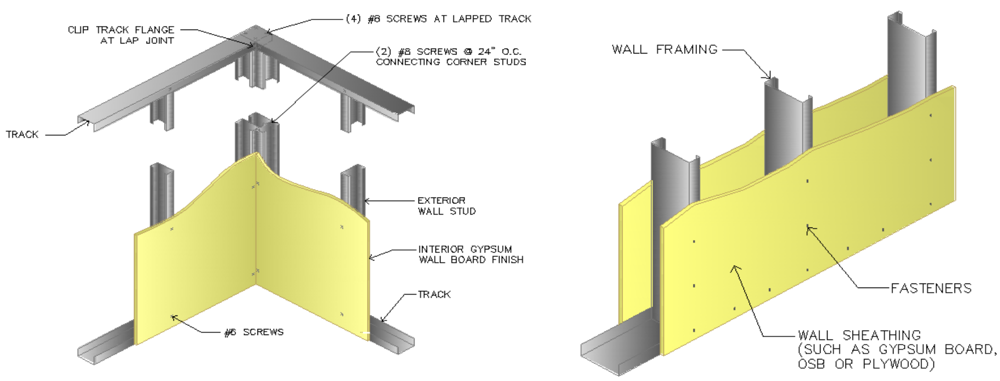


Fig. 5.13. Light gauge steel framing-wall building detail

Panelised constructions are made of bidirectional elements (wall and floor sub-frames and roof trusses), which are prefabricated in factory. Thermal insulation and some of the lining and finishing materials may also be applied to the steel sub-frame to form panels with a consequently reduction of execution times. This system is particularly indicated to build houses characterized by a large number of repetitive elements. [28]

Fig. 5.14. Factory prefabricated wall *light gauge steel cassettes*

Alternative forms of wall assembly used in low-rise steel framed construction are realized with light gauge steel cassettes. The basic arrangement of this system consists of C-shaped cassettes that span vertically between top and bottom tracks to form panels which are storey height. The wall construction is then completed internally by insulation and dry lining. [28]

Stick built and panellized systems can be assembled as Balloon Frame or Platform Frame. The Balloon Frame system was introduced by George Washington in 1830 for wooden structures (Sprangue P., 1981). In this system, the wall can be structural continuous from foundation to the roof and the floors are ailed to the front or the side of the columns. The joists are fixed into a track attached to the face of the stud wall. This attachment is usually a direct screw-fixed method or the floor system may be ‘hung’ on the wall by means of a Z section. Advantages of this method are the possibility to work on wide surfaces, it permits better adaptability to tolerance ‘creep’ and vertical alignment and it allows good air tightness. On the other hand, the difficulty of erection wide surfaces on site represents a significant disadvantage. [28]

In the Platform-frame system, the structure is built storey by storey, so that each ones can serve as working platform for the construction of the floor above. The walls are not structurally continuous and loads are transferred through the floor structure from the upper to the lower walls by means of mechanical connectors. Framing ensures the transfer of floor loads directly onto the studs but requires reinforcement of the joist webs in order to eliminate the potential of web crippling.[28]

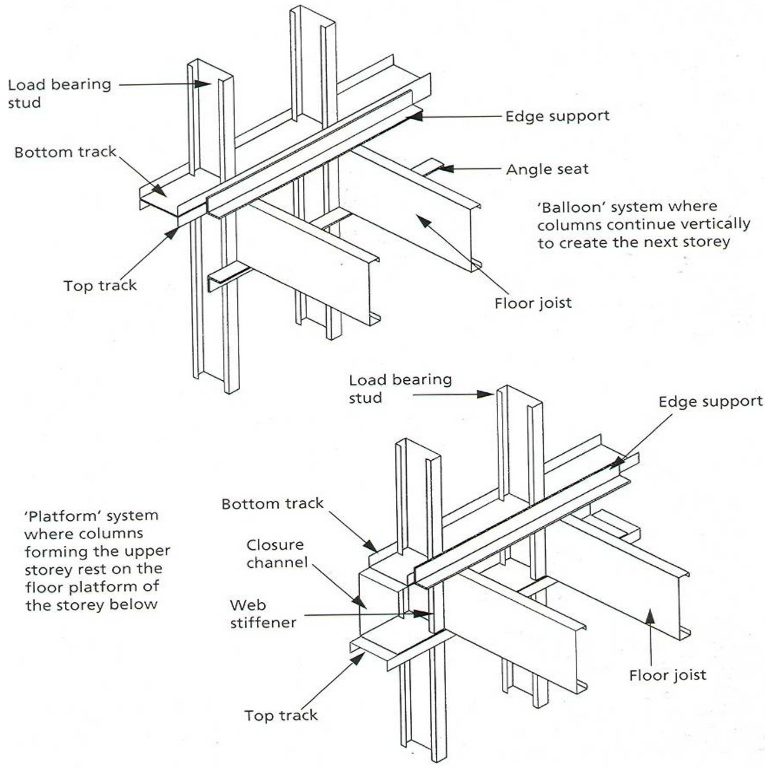


Fig. 5.15. Balloon Frame vs. Platform Frame.

Modular construction uses pre-engineered volumetric units that are installed on site as fitted-out and serviced 'building blocks'. The use of modular construction is directly influenced by the client's requirements for speed of construction, quality, added benefits of economy of scale, as well as single point procurement. These benefits may be quantified in a holistic assessment of the costs and value of modular construction in relation to more traditional alternatives. [60]

Light steel framing is an integral part of modular construction as it is strong, light weight, durable, accurate, free from long-term movement, and is well proven in a wide range of applications. It is part of an established infrastructure of supply and manufacture and supported standards and various design guides.

The motivation for using modular construction generally arises because of over-riding client requirements for speed of construction, improved quality, and for early return of investment. Furthermore, there is a noticeable trend to use modular construction in social housing, where speed of construction is allied to economy of production scale, and to reduced disruption in congested inner city sites. [60]

The benefits of modular construction are:

- reduced construction costs, especially when combined with economy of scale production (10%+)
- much reduced construction time on site (50 to 60%)
- increased profitability of the industry due to economy of manufacturing scale
- increased site productivity (up to 50%)
- greater certainty of completion on time and to budget

- much reduced wastage in manufacture and on site
- greater reliability and quality.[60]

Modular or volumetric constructions use pre-engineered modular units, which are transported from the factory to the site and installed as fitted out. Frames are welded together into the shop by using cold-formed galvanized steel sections together with window and door openings which are formed at this stage. Two generic forms of modular construction exist: a) continuously supported modules, where vertical loads are transmitted through the walls to a continuous foundation ; b) open-sided or point-supported modules, where vertical loads are transmitted through corner and intermediate supports to point-foundations. Point-supported system requires deeper edge beams than continuously supported modules. In both systems, forces are transferred by the module-module connections assisted by horizontal bracing, when necessary (Lawson and Ogden, 2008). Therefore, great importance has to be given to the junctions between the various members, because this determines the physical properties of the whole structure. The application of modular construction is the most economical for the repetitive production of a large number of similar sized units. Modular toilets, bathrooms, lifts, service plants and roof-top extensions can also be introduced beside of existing buildings to create new spaces and improve the quality of life for the users. The different construction systems are often combined together in order to reduce the construction times without losing in terms of spatial organization. [28]


Fig. 5.16. Continuously supported module and modular unit by Kingspan.

The main forms of volumetric construction include:

Shipping Container: This method relies on the strength and flexibility of the shipping container designs. These elements are delivered in 2.5m wide by either 20m or 40m long. The interior is complete with fixtures and fittings for temporary offices, toilets, storage, kitchens. The main use of these stackable container-like structures is in risk areas such as construction sites.

Rigid frame construction: This method relies on a main rigid structural steel frame that is then completed with a roof and walls. This system allows for side and end walls to be left open to create large interior spaces. The level of finishes varies to suit the client needs. This system is used for permanent or temporary buildings.

Panelised system: These modules replicate the timber or light steel frame methods, and are generally designed for permanent construction in housing or small offices. The structural stability relies on the diaphragm effect of the walls, floors and ceilings. [59]

Using volumetric construction has been estimated to reduce waste on site by between 70% and 90% of what might be generated using more traditional construction approaches. The modules sent to site are almost completely finished, so that the work required on site is rather limited and, hence, generates a negligible amount of waste. On site, the installation of volumetric modules generated waste through excavation waste, small amounts of concrete from foundations, small amounts of plastic packaging from independently delivered items, some packaging and protection necessary for transportation and protection of the modules, small amounts of waste generated by assembly of modules on site (e.g. finishes at junctions). [59]

Volumetric offsite construction also impacts the carbon footprint of the building by reducing the total number of deliveries to sites by 90%, by decreasing the average travel distance of the labour force to the site by 75%, and by ensuring that the waste generated at the factory is segregated at source and recycled appropriately. The report "'CO2 emissions from use, scrapping and manufacture of modular buildings" recently published by Arup Research and Development stated that up to 67% less energy is required to produce a modular building compared to an equivalent traditionally built project. [59]

Prescriptive methods for light gauge steel framing

The *Prescriptive Method* was developed as an interim guideline for the construction of one-and two-family residential dwellings using cold-formed steel framing. The goal of the *Prescriptive Method* is to present prescriptive criteria (tables, figures, guidelines) for the construction of one-and two-story dwellings framed with cold-formed steel members. Prior to this document, there were no prescriptive standards available to builders and code officials for the purpose of constructing cold-formed steel houses without the added expense of a design professional and other costs associated with using a "non-standard" material for residential construction. The method applies to buildings that conform to the application limits identified in the next table. [40]

Applicability Limits			
Application	**Limitation** metric (imperial)		
Building Area	600 m^2 (6460 sq ft) maximum		
Number of Stories	3 storey maximum		
Building width	13.4 m (40 ft) maximum from eave to eave including 0.6 m (24 in) x 2 overhang		
Building Length	18.3 m (60 ft) maximum		
Hourly Wind Pressure, q (1/30)	Up to 0.6 kPa (12.5 psf)		
Specified Roof Snow Load	Up to 2.5 kPa (52.2 psf)		
Seismic Parameters	Z_a	V	Z_z
	1	0.05	0
	2	0.05	1
	4	0.10	2

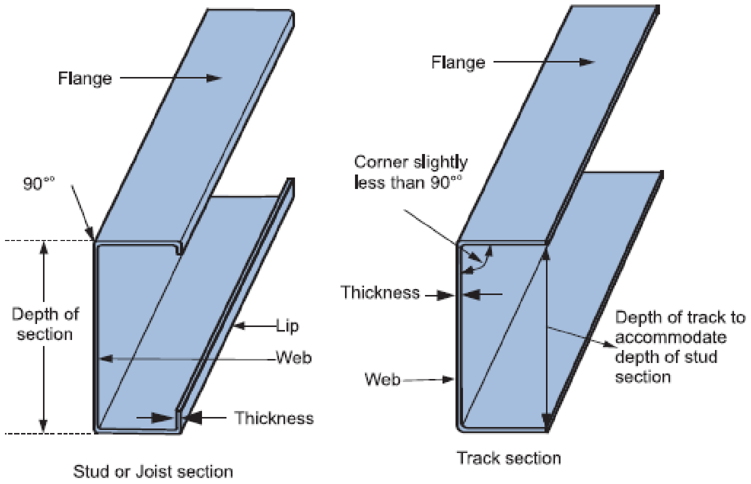


Fig. 5.17. Framing Member Cross-Sections

The stud and joist sections have flanges stiffened with a lip to increase member strength. Track sections are made with unstiffened flanges that are angled slightly inward to temporarily hold the studs in place before being secured with a fastener, and also to allow the studs to bear directly on the track web.

The standard loadbearing residential steel framing members used in Canada are listed in next figure. These sections, spaced up to 610 mm (24 in) on centre, can be used for a variety of floor and wall loading conditions. Non-standard sections are also available or can be manufactured by special request, but standard sizes are recommended to ensure ready supply and to enable standardized load tables.[40]

Standard Loadbearing Member Sizes (nominal dimensions)				
Commonly Used Application	**Web Depth mm (in)**	**Flange Width mm (in)**	**Design Thickness mm (in)**	**MinimumThickness mm (in)**
Studs (nominal 2 x 4)	92.1 (3-5/8) 92.1 (3-5/8) 92.1 (3-5/8)	41.3 (1-5/8) 41.3 (1-5/8) 41.3 (1-5/8)	0.879 (0.0346) 1.146 (0.0451) 1.438 (0.0566)	0.836 (0.0329) 1.087 (0.0428) 1.367 (0.0538)
Studs, Headers & Joists (nominal 2 x 6)	152 (6) 152 (6) 152 (6)	41.3 (1-5/8) 41.3 (1-5/8) 41.3 (1-5/8)	0.879 (0.0346) 1.146 (0.0451) 1.438 (0.0566)	0.836 (0.0329) 1.087 (0.0428) 1.367 (0.0538)
Joists, Headers & Lintels (nominal 2 x 8)	203 (8) 203 (8) 203 (8) 203 (8)	41.3 (1-5/8) 41.3 (1-5/8) 41.3 (1-5/8) 41.3 (1-5/8)	0.879 (0.0346) 1.146 (0.0451) 1.438 (0.0566) 1.811 (0.0713)	0.836 (0.0329) 1.087 (0.0428) 1.367 (0.0538) 1.720 (0.0677)
Joists & Headers (Nominal 2 x 10)	254 (10) 254 (10) 254 (10)	41.3 (1-5/8) 41.3 (1-5/8) 41.3 (1-5/8)	1.146 (0.0451) 1.438 (0.0566) 1.811 (0.0713)	1.087 (0.0428) 1.367 (0.0538) 1.720 (0.0677)
Joists & Headers (Nominal 2 x 12)	305 (12) 305 (12) 305 (12)	41.3 (1-5/8) 41.3 (1-5/8) 41.3 (1-5/8)	1.146 (0.0451) 1.438 (0.0566) 1.811 (0.0713)	1.087 (0.0428) 1.367 (0.0538) 1.720 (0.0677)

Tab. 5.2 Standard member sizes

Standard Non-Loadbearing Member Sizes (nominal dimensions)			
Commonly Used Application	**Web Depth mm (in)**	**Flange Width mm (in)**	**Minimum Uncoated Thickness mm (in)**
Interior Bulkhead Construction	41.3 (1-5/8)	31.8 (1-1/4)	0.455 (0.0179)
Miscellaneous Interior Framing	63.5 (2-1/2)	31.8 (1-1/4)	0.455 (0.0179)
Interior Non-Loadbearing Studs	92.1 (3-5/8 or 3-1/2) 152 (6)	31.8 (1-1/4) 31.8 (1-1/4)	0.455 (0.0179) 0.455 (0.0179)

Tab. 5.2 Standard member sizes

Foundation

Cold formed steel housing for their lightness does not need deep foundations. They can easily set on poured concrete walls or slab-on-grad foundations. In particular, in the second case 300-500 mm high slab foundations can be realized even on poor soils without deep digging. This is the simplest form of foundation for most light steel residential structures. Using this form of foundation, bearing walls may be supported on thickened portions of the slab and changes in ground level can be easily accommodated. [28]

Fig. 5.18. Typical foundation systems [28]

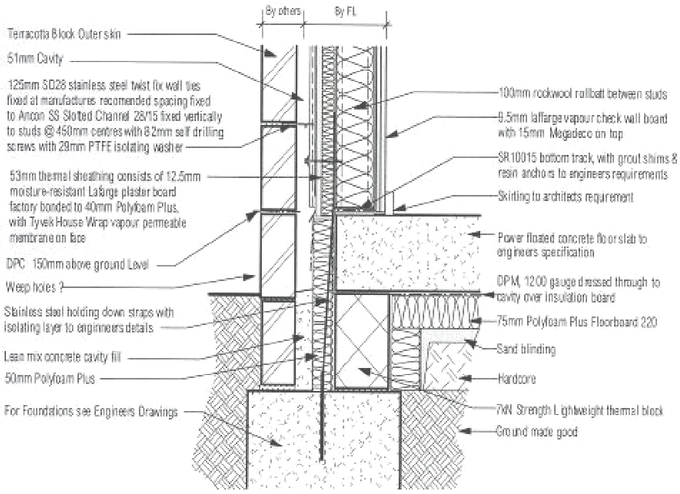


Fig. 5.19. Concrete slab on grade detail [28]

Floors

Floors are realized with horizontal load bearing members (joists) sheathed with gypsum and wood-based panels. Joists are usually C- or Z-shaped members spaced at 300-600mm and fastened at each ending to a floor track. Web-stiffeners are installed at both joists ends in order to strengthen the member against web-crippling. Floor spans will range from about 4 meters to 6 meters depending upon the depth and type of the used joist (Access steel, 2005c). The spans can be taken from manufacturer's published tables but should be checked by the responsible structural engineer. When the span is very large, squat C-shaped members (blocks) are installed in perpendicular directions to the joists, in order to stiff them along the length, and flat straps are fastened to the bottom side to assure continuity between joists and blocks. [28]

To obtain an adequate in-plane bracing either X-bracing realized by flat strips fastened on the bottom side or the sheathing itself can be adopted as bracing system. In particular, a drywall ceiling makes acceptable lower-flange bracing, but in a basement, the usual approach is to run a strip of steel strapping at the centre of the joist span for the entire length of the floor section, securing it at each joist with one screw. The blocking can be narrower than the joists themselves, and is fastened with clip angles. Moreover, cantilevered joists can be realized but they require a web stiffener where they pass over the supporting wall. [28]

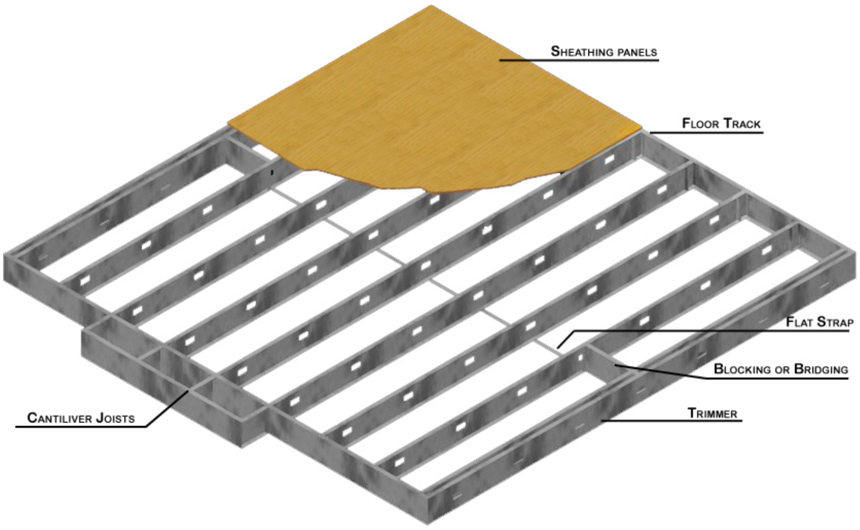
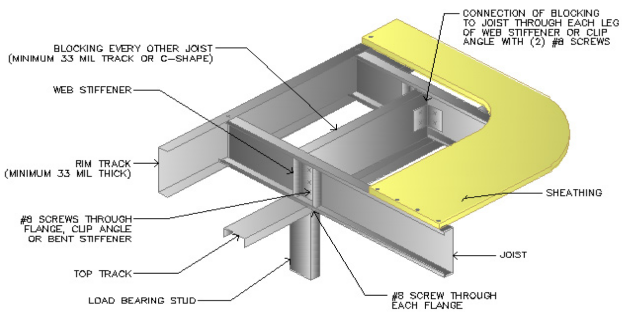


Fig. 5.20. Typical floor framing [28]

There are various methods of floor system anchorage to foundation walls for a steel frame house:

1. Use a wood sill plate in the same manner as in a wood frame house; or
2. Attaching the closure channel directly to the foundation; or
3. Use a nested stud and track. This technique employs a piece of steel track in combination with stud to replace the wood sill plate. [40]



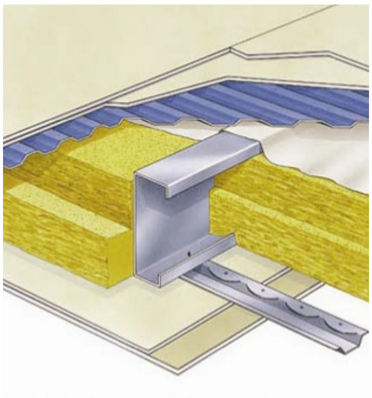
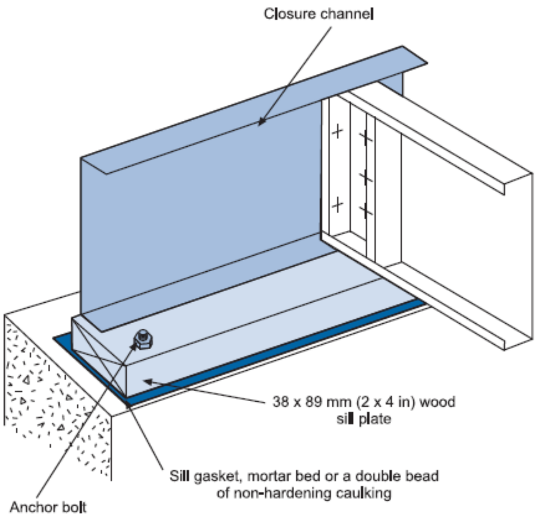


Fig. 5.21. Light gauge steel framing-floor building details

It is important to remember that any steel close to or in contact with concrete must be corrosion resistant. With every type of system a sill gasket, a double bead of non-hardening caulking, or a mortar bed must be provided under the sill plates (or under the closure channel if a sill plate is not used) as required by local building codes, this prevents direct contact between the steel and concrete. [40]



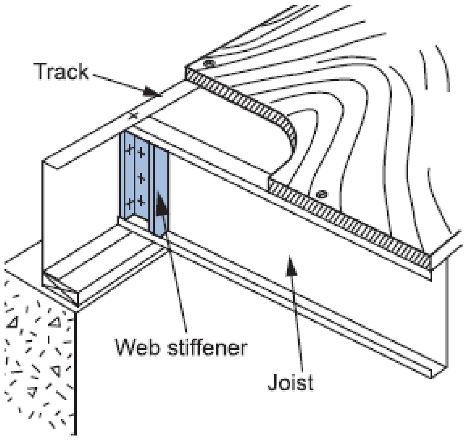
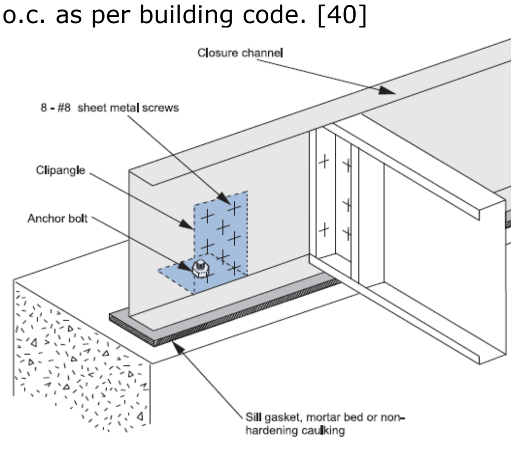


Fig. 5.22. Wood Sill Plate *Floor to Wood Sill Connection[40]*

In the wood sill plate anchorage technique a wooden member, usually 38 x 89 mm (2 x 4 in), is fastened to the foundation via anchor bolts. A double bead of non-hardening caulking, or a mortar bed must be provided between the sill plate and the foundation. The closure channel or rim joist must be securely fastened to the wood sill plate by means of a steel plate, or through the flange of the closure channel into the plate. [40]

Using direct bearing anchorage the closure channel/rim joist can be anchored directly to the foundation without the use of a sill plate. This eliminates issues of shrinkage experienced with wood but could be problematic if the foundation is not even. As with the wood sill plate method a sill gasket, a double bead of non-hardening caulking, or a mortar bed must be provided between the foundation and the rim joist. [40]

There are two ways to connect the rim joist to the foundation: by means of a clip angle or with an anchor tie. A clip angle is used in conjunction with an anchor bolt. The clip angle is fastened with screws to the rim joist and bolted to the foundation, they are spaced according to the required anchor bolt spacing, at least every 2400 mm (94 in) o.c. Anchor ties are cast directly into the foundation and then fastened to the exterior side of the closure channel. The ties must be spaced in accordance with the layout of the xbracing used for wind and racking resistance. As with all fastening systems, the spacing may be no greater than 2400 mm (94 in) o.c. as per building code. [40]



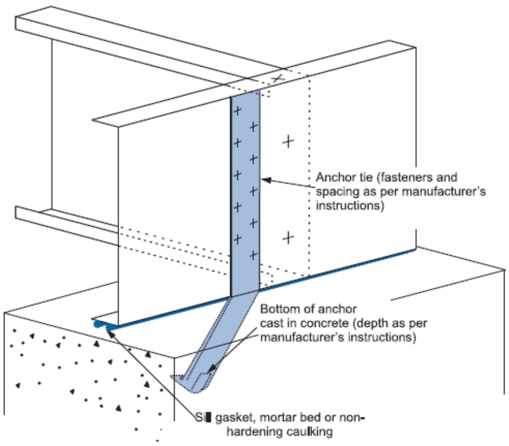


Fig. 5.23. Clip Angle without Sill Plate *Anchor Ties[40]*

The nested track and stud sill plate anchorage system takes advantage of the ability of a steel sill plate to create a level surface while avoiding the shrinkage issues of wood. A nested track and stud are used as a sill plate, anchored with anchor ties. A closure channel is screwed onto the track and stud. Attachment of the closure channel to the sill plate and the sill plate to the foundation is the same as described under the wood plate attachment requirements. [40]

Floors must be designed and built to resist all superimposed loads and transfer these loads to the exterior walls and foundations. Floors support not only their loads but often the loads from roofs and other floors as well, before ultimately transferring the loads to the foundation. Floors must resist deflection and minimize vibration. They must also provide an acceptable surface for finished flooring materials. Components of the floor system such as floor joists, flat strap bracing, web stiffeners, intermediate support beams and clip angles can all be selected without additional engineering.

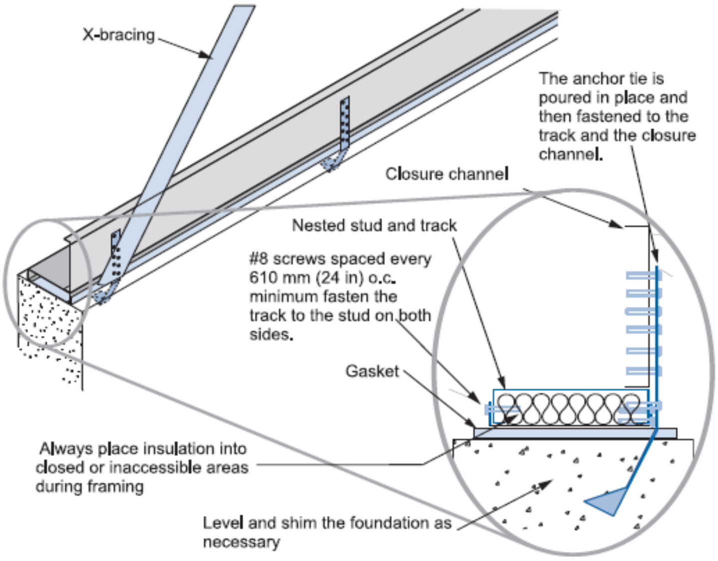


Fig. 5.24. Nested Track and Stud Detail[40]

When supported by steel framed walls, a steel framed floor shall be constructed with floor joists in-line with loadbearing studs located below the joists. Generally, the maximum distance between the centre lines of the joist and the stud shall be limited in accordance with the next figure.

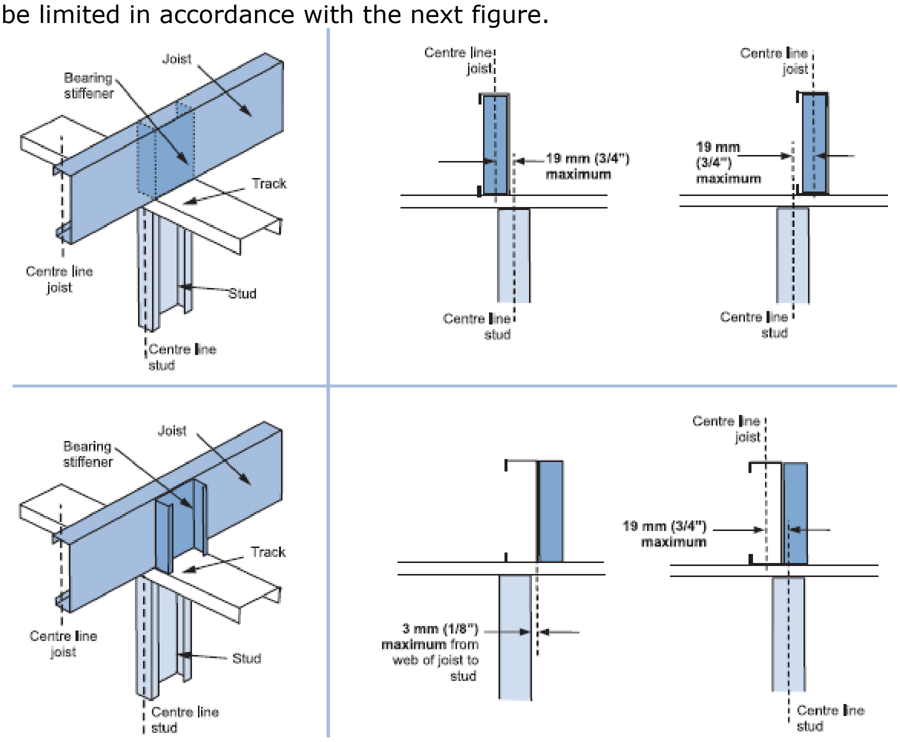


Fig. 5.25. In-line Framing Tolerance Limits [40]

Beams for lightweight steel construction normally consist of structural steel beams or built-up joist and track members. Built-up lightweight steel members must be engineered. The built-up members are fastened together with screws at 610 mm (24 in) o.c. An alternative method of connecting built-up members is by welding. [40]

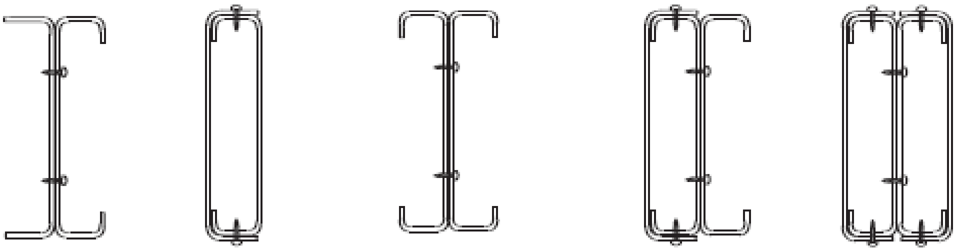


Fig. 5.26. Built- Up Sections [40]

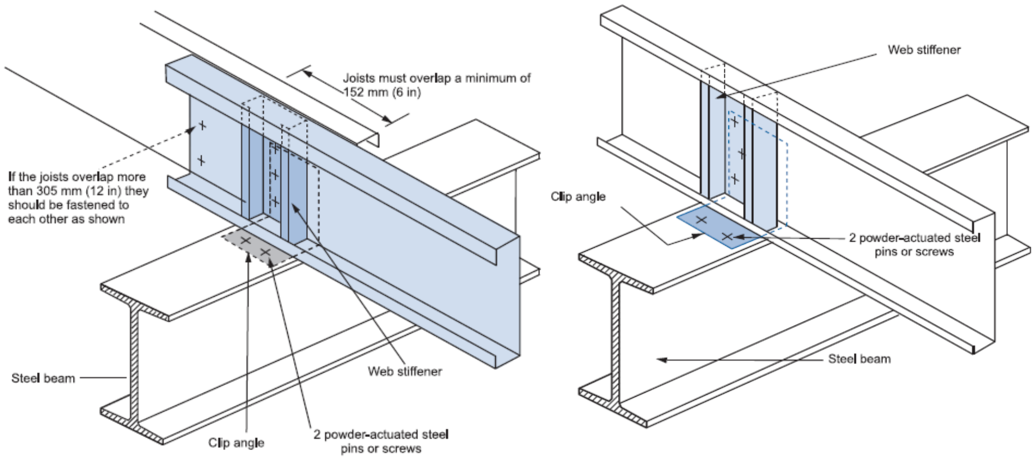


Fig. 5.27. Lapped and Continuous Joists Supported on a Steel Beam [40]

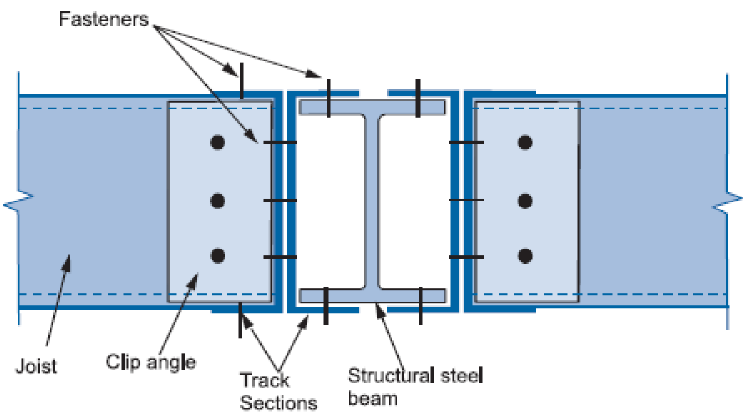


Fig. 5.28. Flush-in-Floor Joists with Steel Beam [40]

Closure channels, made of track sections, are available to accommodate all sizes of joists. The depth of the closure channel is determined by the joist depth (e.g. if using 203 mm (8 in) joists then the closure channel must also be 203 mm (8 in). The standard thickness of closure channels is 1.146 mm (0.0451 in).

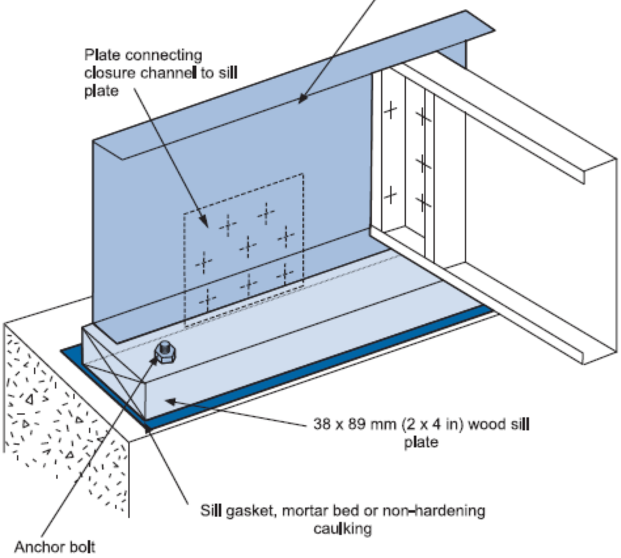


Fig. 5.29. Closure Channel [40]

If supported by a loadbearing wall, it is important that the web of the floor joists line up so that the centre lines of the members are within the limits. This will ensure that loads are transferred properly from the floor joists to the wall studs. Outside to outside dimensions of the closure channels must be correct. Floor joists may not be spliced. All webs should face the same direction. The only exceptions to this are cases where joists are single spans supported on an intermediate beam. In this case the joists must be lapped with the webs back-to-back. [40]

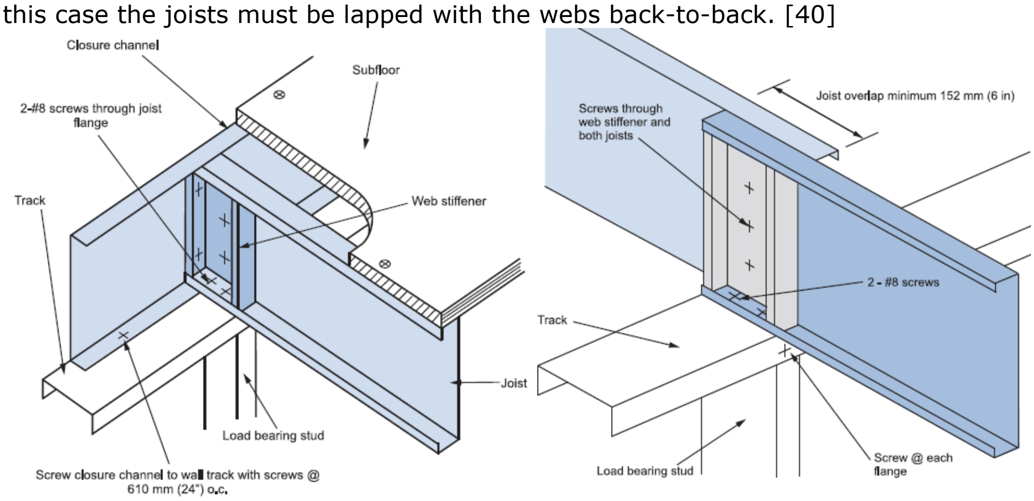


Fig. 5.30. Floor Joists and Lapped Joists Supported on a Loadbearing Stud Wall [40]

A web stiffener is used in all locations where a concentrated load acts on a floor joist or track section. A web stiffener is a short piece of loadbearing stud with a thickness at least 0.879 mm (0.0346 in). The stiffener has a 38 mm (1-1/2 in) wide flange to allow it to fit within the 41 mm (1-5/8 in) flanges of the joist. The minimum length of the stiffener shall be the depth of the member being stiffened minus 9 mm (3/8 in). Stiffeners can be installed on either side of the joist web, fastened to the joist with at least 3 screws. [40]

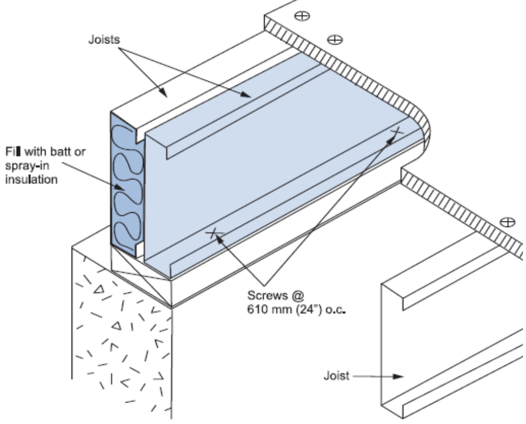
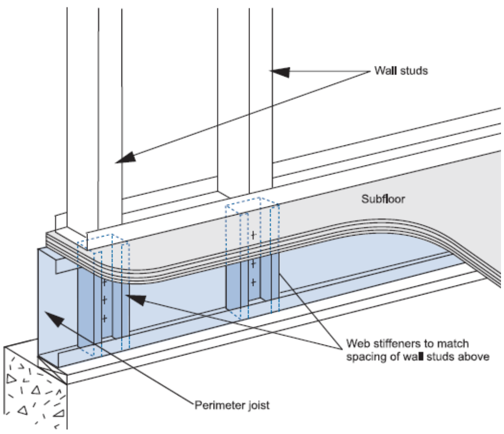


Fig. 5.31. Perimeter Joist Placement



Web Stiffeners in a Perimeter Joist [40]

Floor joist bridging (in the form of flat strap, notched channel or through-the-knockout channel bridging) and blocking (solid C-channel or track) must be installed in all steel framed floors. It is necessary to brace floor joists to prevent the rolling or shifting of individual members out from under the load. During construction, avoid walking on floor joists until the subfloor is screwed in place. Before applying heavy loads, such as those from storing of materials (e.g. drywall) the bottom flange of each floor joist must be braced. [40]

Solid blocking is typically made from C-sections that are the next size smaller than the joists being braced. For example, a 152 mm (6 in) section is used to block a 203 mm (8 in) joist. This allows the blocking to be connected to the joists with clip angles using 2 screws per angle leg. [40]

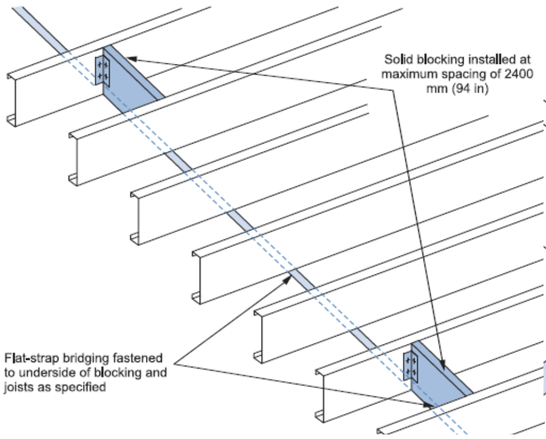
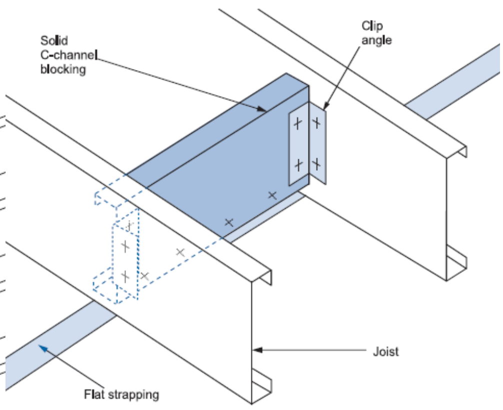


Fig. 5.32. Floor Bridging and Blocking Layout



Solid C-Channel Blocking [40]

Blocking is installed between joists at a maximum spacing of 2400 mm (94 in), usually every fifth joist space is adequate, and at the termination of all bridging straps. Flat strap or notched channel bridging is fastened to the underside of joists and to the blocking to provide lateral support to the joists. The bridging must be fastened to the bottom flange of each joist using at least 1 screw.


Fig. 5.33. Example of web stiffener and double joists realized in C. House

Bridging straps should be at least 38 mm wide by 0.879 mm (1-1/2 in x 0.0346 in) thick and spaced not more than 2400 mm (7 ft -10 in) from each support or other rows of bridging. The ends of the steel strapping should be fastened to the blocking with at least 4 screws. Alternatively, the strap can be anchored directly to the exterior wall. For flat strap bridging to be effective it must be fastened without slack. Strapping should be pulled taught as it is fastened. If a splice is made in the strapping, it must be overlapped and screwed to a blocking section. [40]

The subfloor acts as bracing for the top flanges of the floor joists. The subfloor is fastened to the flanges of joists using bugle-head screws spaced 152 mm (6 in) o.c. along the sheet edges and 305 mm (12 in) o.c. in the field. The minimum edge distance must be at least 10 mm (3/8 in). The thickness will depend on the material used for subflooring and the spacing of the joists. Waterproof construction adhesive (the same type as for wood framing) is recommended to improve the connection. Floor finishes are installed conventionally over the subfloor. [40]

Thickness of Subflooring				
Maximum Spacing of Supports mm (in)	Minimum Thickness mm (in)			
	Plywood and OSB, 0-2 Grade	OSB, 0-1 Grade, and Waferboard, R-1 Grade	Particle Board	Lumber
400 (16)	15.5 (0.62)	15.9 (0.636)	15.9 (0.636)	17.0 (0.68)
500 (20)	15.5 (0.62)	15.9 (0.636)	19.0 (0.76)	19.0 (0.76)
600 (24)	18.5 (0.74)	19.0 (0.76)	25.4 (1.016)	19.0 (0.76)

Tab. 5.3 Recommended thickness of subflooring

Floor openings are framed with the use of header and trimmer joists. Track and joist sections making up the trimmer joists must be full length and cannot be spliced. Trimmer joists for each opening should form a closed box section at the opening providing a flat surface to connect headers. [40]

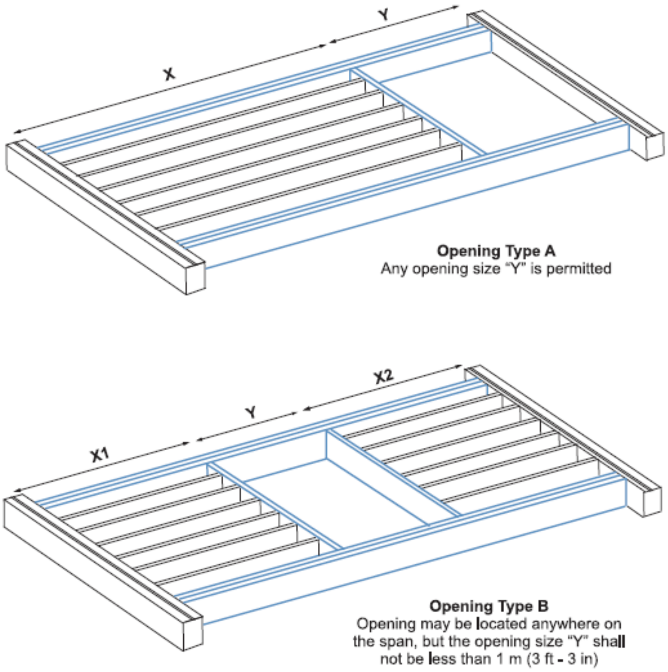


Fig. 5.34. Floor Opening Types [40]

Track sections can be combined with "C" sections to form built-up sections to use as floor beams, headers, lintels, trimmers, jamb or jack studs, and at other locations requiring extra strength. All built-up sections should be made from members of equal thickness, and fastened together at least every 610 mm (24 in) o.c. The sections used in these built-up members must be continuous lengths, unless their purpose is non-structural (i.e. closing off rough openings). [40]

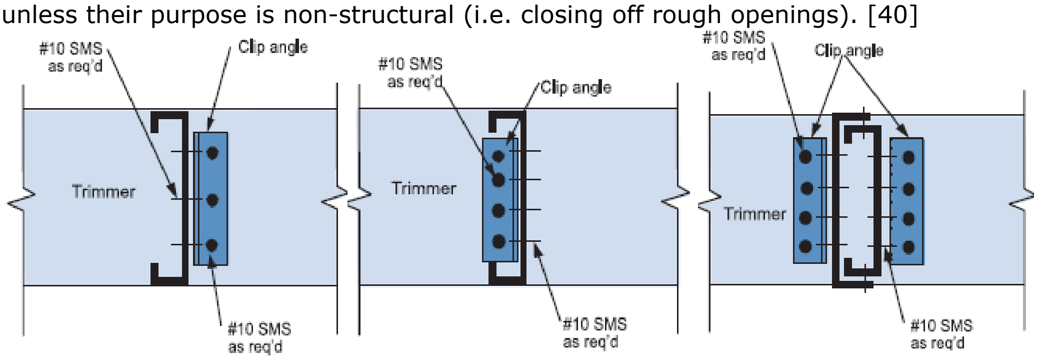


Fig. 5.35. Header to Trimmer Connections for Floor Openings [40]

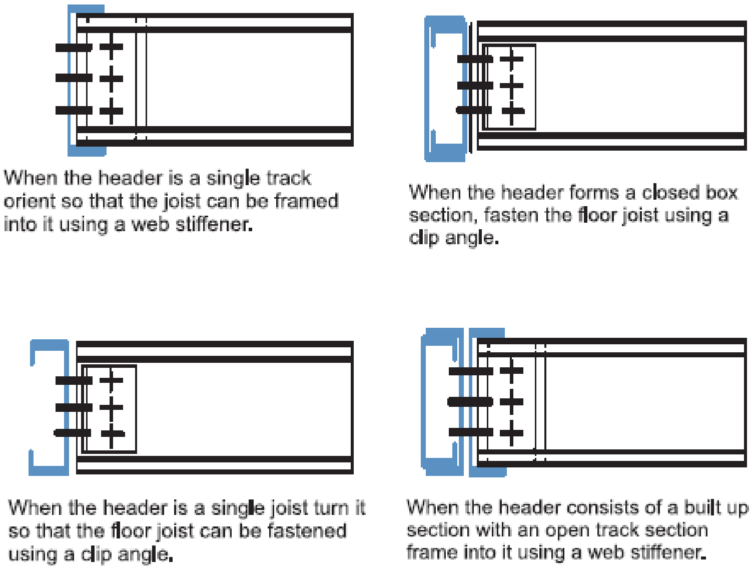


Fig. 5.36. Tail Joist Attachment to Different Header Types [40]

Floor joists can be connected to headers either by clip angle or if a track section forms part of the header, floor joists can be framed into the header using web stiffeners.

Wall studs

Wall systems must be designed and constructed to transfer loads from roofs and floors to the foundation. They must be able to resist racking from wind and earthquakes. Walls must also provide backing for interior and exterior finishes and control the flow of heat, moisture and air into and out of the dwelling. [40]

Walls can be divided in load bearing walls and non-bearing walls. In the first case the principal structure is realized with studs, vertical load bearing members spaced at 300-600mm, in line with floor joists, and fastened at each end to wall tracks, that have the function of band and distributing loads among the studs. Sometimes squat lipped channel members are installed to strengthen the stud along the height. [28]

The wall design can change in dependence of the related function. When the walls represent the lateral load resisting system, then they have to carry vertical loads transferred from upper floors and roof and they have to resist to horizontal loads as wind and seismic actions. In particular, the ability to resist to horizontal in-plane actions can be achieved by different systems: a) X bracing; b) installing horizontal steel strapping on both wall sides at mid-height and in-line blocking at ends of all straps; c) fastening structural sheathing boards on one or both studs sides, d) introducing a structural sheathing on one side and horizontal steel strapping on the other side (mixed solution). In particular, structural sheathings have to be installed with the long direction parallel to the studs and have to cover the full height. [28]

Moreover in order to assure the wall from up-lift, due to horizontal in-plane actions, hold down anchors have to be introduced at the end of each resistant wall.

The result is a sandwich construction where each panel can bear perpendicular pressure on its surface as well as horizontal in-plane loads. The internal wall cavity is ideal for inserting cables, pipes and make easy to add equipment. An unlimited range of material can be used as finishing. In particular, the inner surface can be left in the original state or be covered with the desiderate covering: paint, wallpaper, coating, fabric, etc. The outer surfaces can be realized with all the common materials: rough coat, covering, masonry, etc. In practice external walls will vary in thickness from about 70mm to 200mm and internal structural walls from 70mm to 100mm. Non-structural walls, room partitions, will range from about 40mm to 100mm. Section thickness for structural elements will range from 0.09mm to 3.2mm and for non-structural elements from 0.07mm to .09mm (Access-steel, 2005b). [28]

Fig. 5.37. Example of wall corner and hold down anchor realized in C. House

LSF members can be manufactured to any desired length, but the practical limit depends on manufacturer handling, local transportation restrictions, and the number of framers available to handle the material on site. A wall should be a length that can be expediently handled by a two to three person framing crew. Track sections can be spliced to complete a full length wall. It is important that there is no splice within 75 mm (3 in) of a stud. Splices should be attached with 4 screws on each side. No splicing of the wall stud is permitted without details by a design professional. [40]

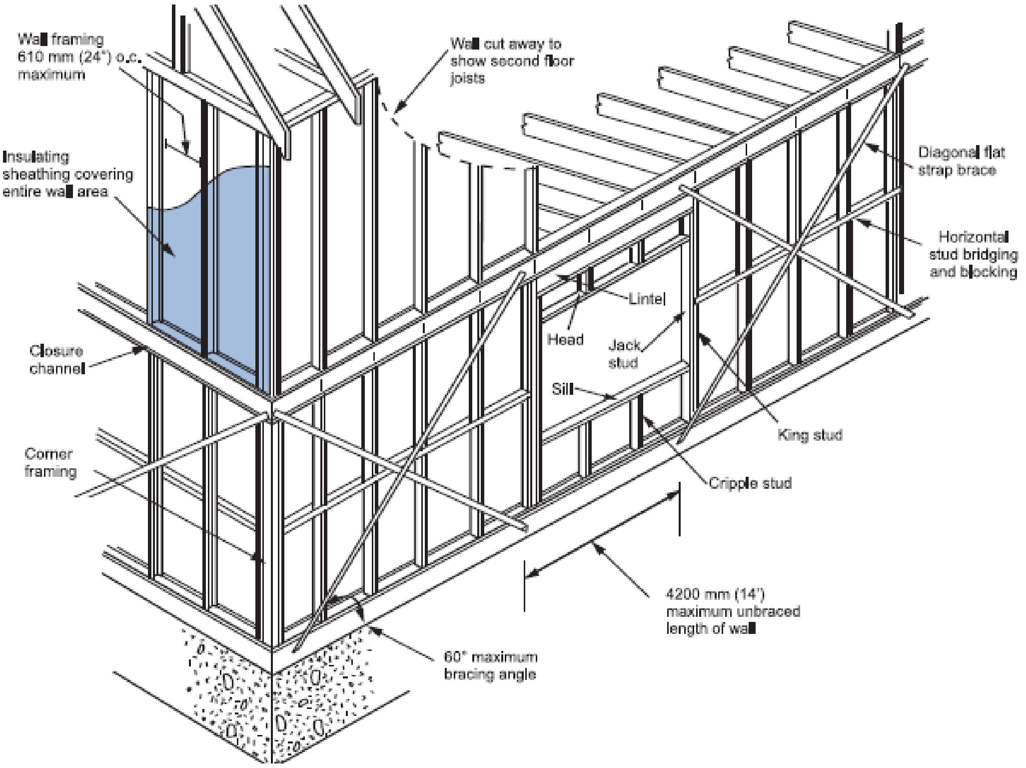


Fig. 5.38. Wall Framing [40]

Loadbearing lightweight steel frame walls should always be framed 'inline'. This means that the studs must bear directly on top of the joists and studs below, because the track section is not a loadbearing element. [40]

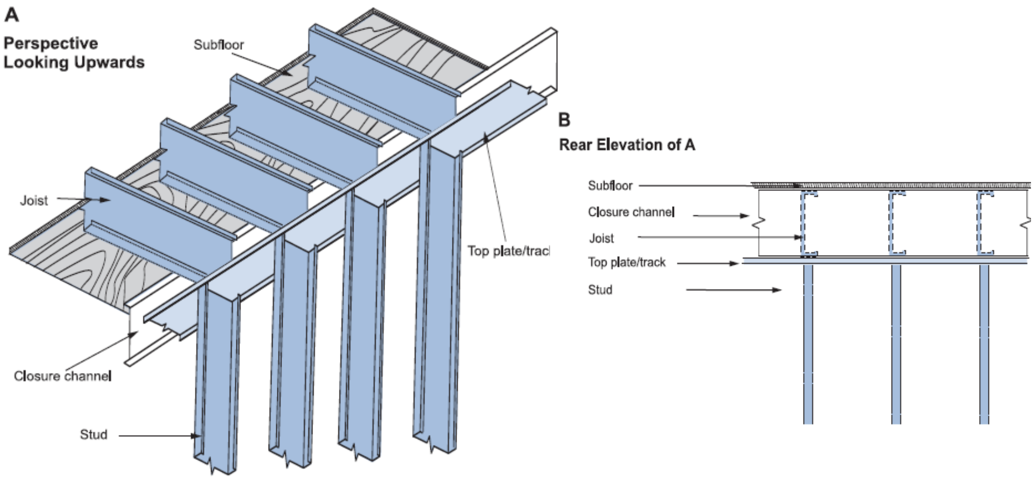


Fig. 5.39. In-line Framing [40]

Studs and track members need to fit snugly to effectively transfer loads. Damaged members often prevent loads from transferring effectively and should not be used. All studs in a wall should be aligned in the same direction. [40]

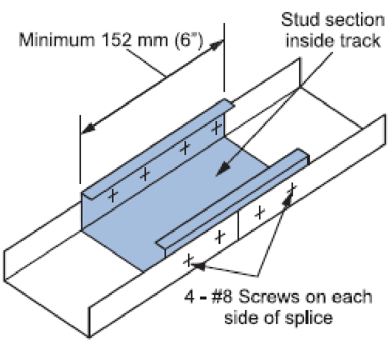
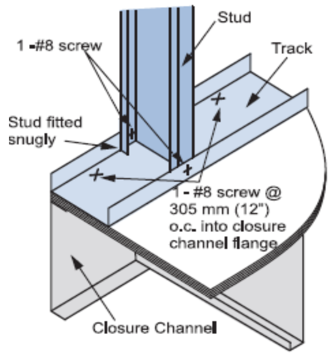


Fig. 5.40. Track Splice



Connecting Studs to Track [40]

Pre-punched or field cut openings must not be closer than 305 mm (12 in) from the top or bottom of the stud. Holes in wall studs must be located in the middle of the web and not exceed 38 mm (11/2 in) in width or 102 mm (4 in) in length. If larger holes are needed, or if they're located within 305mm (12 in) of the end of the stud, the holes need to be properly reinforced, and may need to be engineered. [40]

All corners and intersections require additional studs as backing for drywall. These additional studs must be placed so that there is access to insert insulation. Grommets should be inserted in corner studs to facilitate wiring later, when the studs may be hard to access. [40]

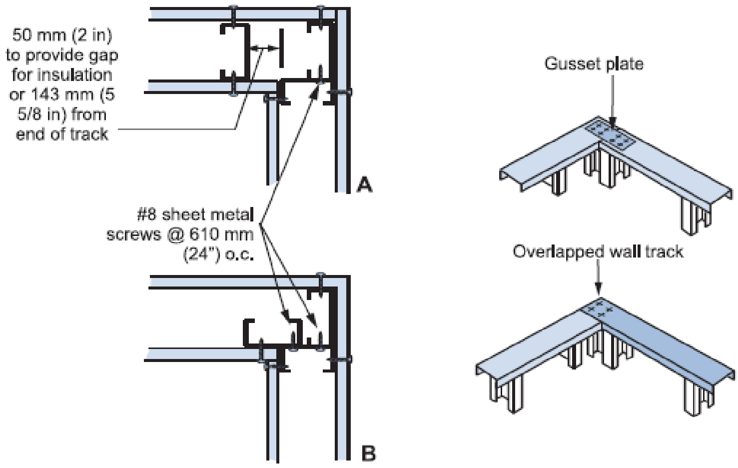
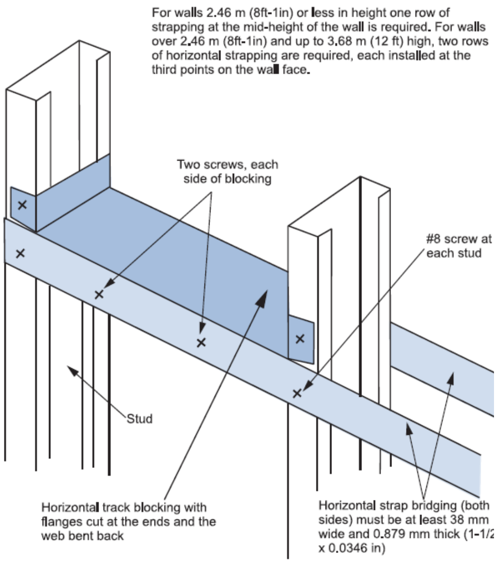


Fig. 5.41. Framing Corners [40]

There are two main types of permanent bracing for LSF walls: horizontal and diagonal. Horizontal flat strap bracing prevents the studs from twisting and is required for all loadbearing walls. Diagonal bracing resists wind and seismic loading (racking) and is required on all exterior walls. [40]

Like floors, loadbearing walls require horizontal strapping and bridging to prevent the twisting of members. Flat strapping is at least 38 mm wide and 0.879 mm thick (1-1/2 x 0.0346 in) sheet steel material. If exterior structural sheathing (e.g. OSB or plywood attached directly to the stud) is used, the flat strap bridging is not needed on that side of the stud, however it must still be installed on the interior stud flange. [40]

Horizontal flat strap bridging must be installed on each side of all loadbearing walls. The strapping must be attached to every stud flange with at least 1 screw. For walls 2.46 m (8 ft-1 in) or less in height, one row of strapping installed at the mid-height of the wall is required. For walls over 2.46 m (8 ft-1 in) and up to 3.68 m (12 ft) high, two rows of horizontal strapping are required, each installed at the third points on the wall face. [40]



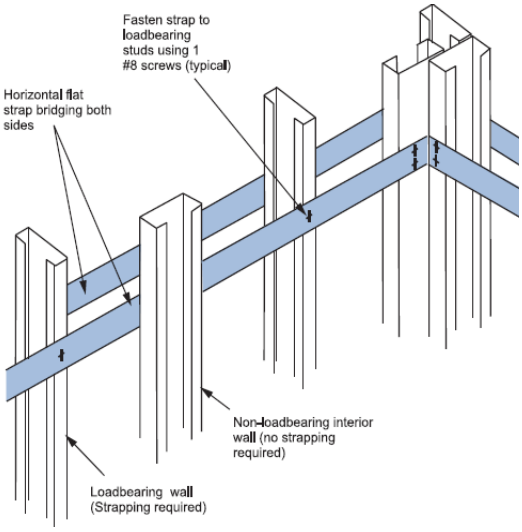


Fig. 5.42. Wall Blocking Detail *Wall Bridging Anchorage [40]*

Diagonal bracing to resist wind pressures and to provide racking resistance under seismic loading is required at every storey on all exterior walls. Diagonal strapping is 75 x 1.146 mm (3 x 0.0451 in) attached to every crossing stud with at least 1 screw. Diagonal bracing must be located at each wall end and the angle to the horizontal of the bracing must not exceed 60 degrees. Double studs are needed when the strap is not connected to the closure channel or perimeter joist. Double studs should always face web to web (back to back) so that all space is insulated.

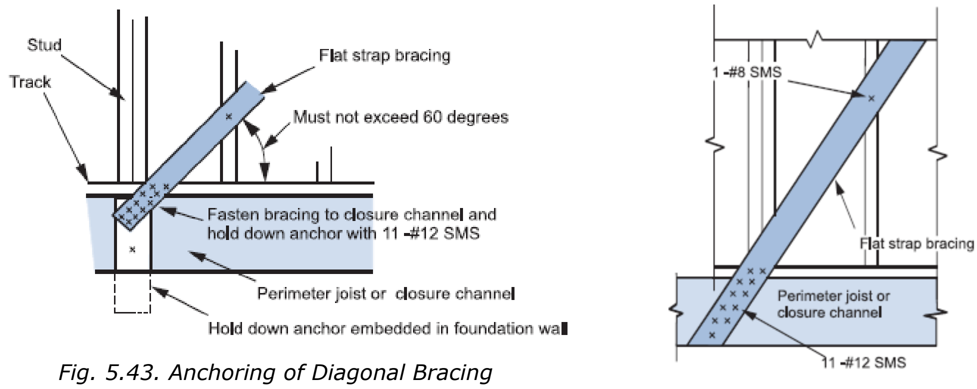


Fig. 5.43. Anchoring of Diagonal Bracing

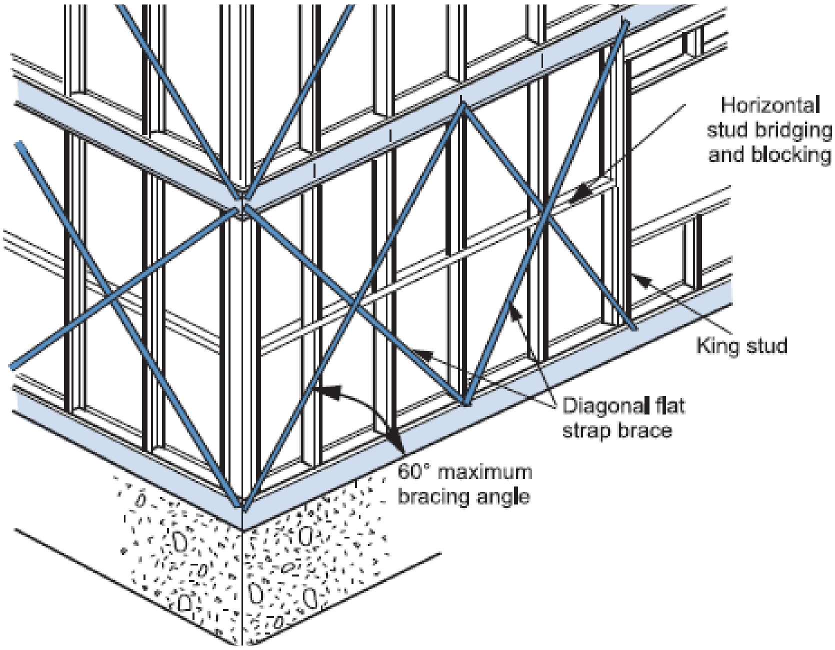


Fig. 5.44. X-Pattern Diagonal Bracing [40]

Structural sheathing (e.g., OSB or plywood) can serve as a substitute for horizontal and diagonal bracing. Sheathing should be installed with the longer axis (length) parallel to the stud framing. The sheathing may be attached to the wall either while on the assembly surface or after the wall is tilted up into place. [40]

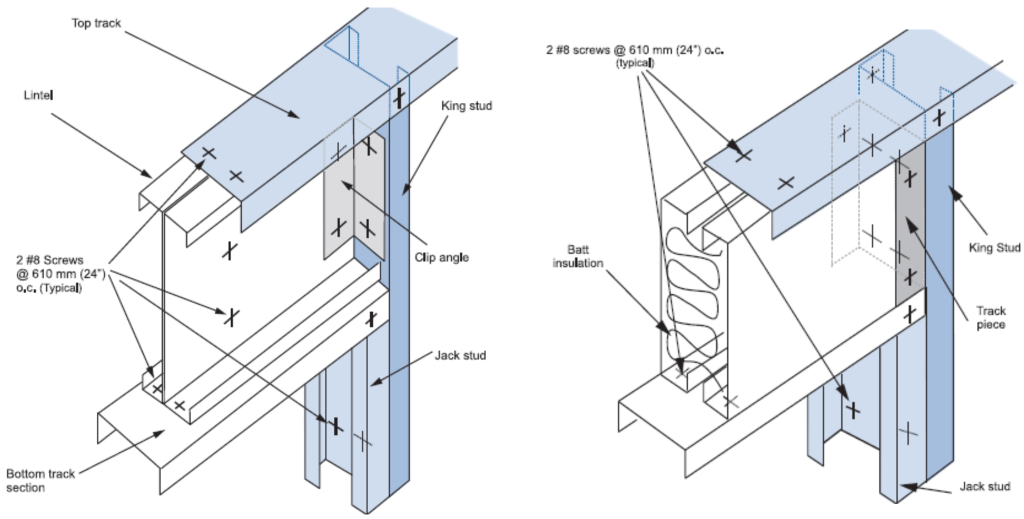


Fig. 5.45. Framing Lintels and Box Lintels[40]

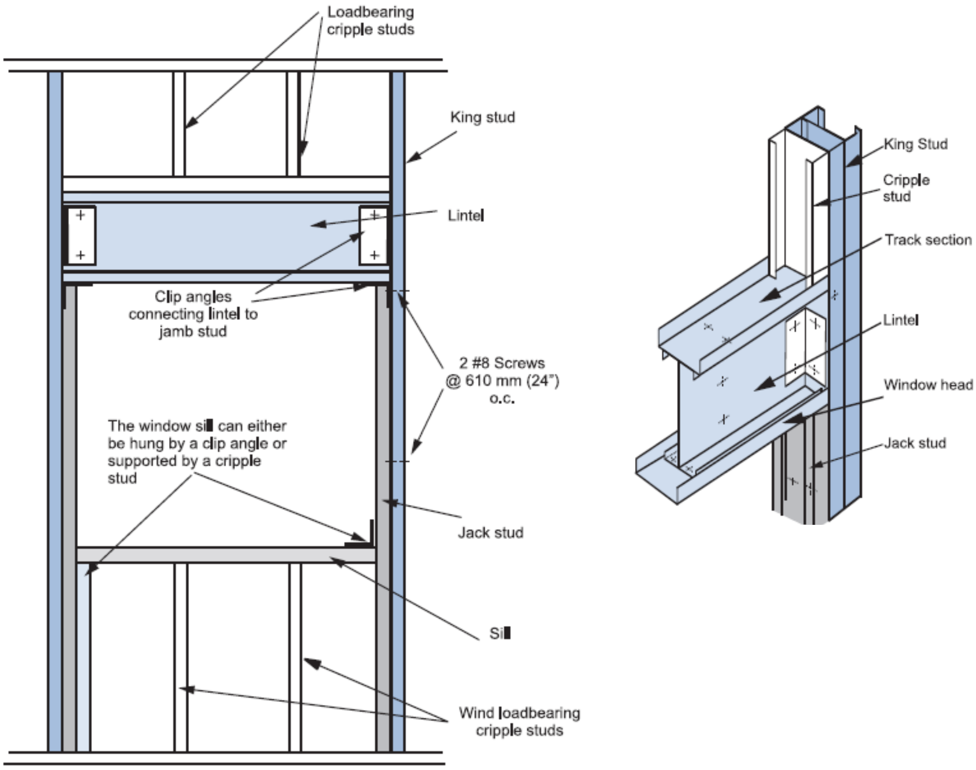


Fig. 5.46. Framing Wall Openings[40]

Roof

Roofs are required to protect the building from exterior elements. The frame of the roof must withstand wind and snow loads and provide support for components such as sheathing and finishes to shed rain and snow away from the building. [40]

Light steel building can present pitched or mono-pitched, flat or curved roofs. In any case, the main structural components of roof framing are: rafters, which are structural framing member (usually sloped) that supports roof loads (typically lipped channel sections), ceiling joists, horizontal structural cold-formed lightweight steel profiles that supports a ceiling and attic loads (typically lipped channel sections); ridge member, horizontal member placed at intersection between the top edges of two sloping roof surfaces and fascia, member applied to the rafter ends as an edge member for attachment of roof sheathing, exterior finishes, or gutter. Moreover as for walls and floors, blocks and flat straps can be introduced to sthrength the in-plane members, and in case of roof openings, headers are placed. Where possible, all roof construction should be aligned with the studs in the supporting walls. Where this is not possible, the use of a robust, load carrying, top track will permit trusses or other roof framing to be located with a reasonable degree of flexibility. [28]

Roofs can be framed using one of two different methods: rafter framing and truss framing. Rafter framing uses the 'stick built' approach in which each member is selected and framed individually. Stick built steel roofs, with the exception of ceiling and roof joists, must be engineered. Pre-engineered lightweight steel truss systems are now being distributed more widely and can be used with the assistance of an engineer. [40]

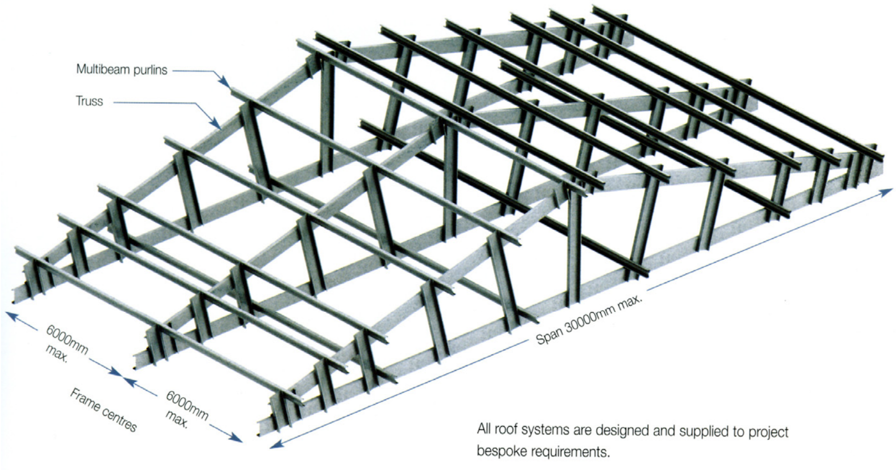


Fig. 5.47. Typical roof framing – Kingspan [28]

Typically for the roofs, the design of ridge and connection between trusses and walls are critical. The roof system must be attached to the wall system via a top plate. This top plate can be made of wood or steel members depending on the builder's preference and the type of roof framing system being used.

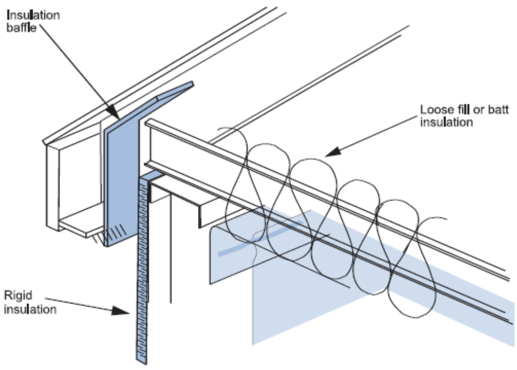


Fig. 5.48. Roof Wall Intersection

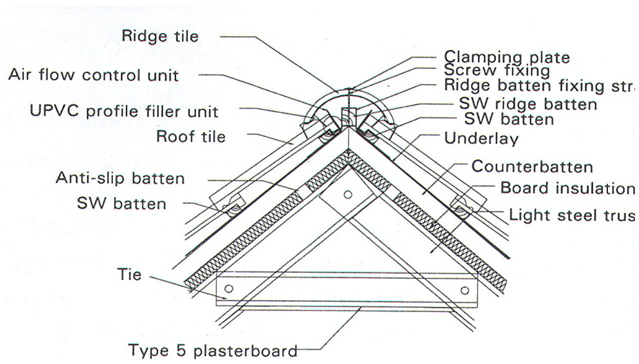


Fig. 5.49. Ridge detail

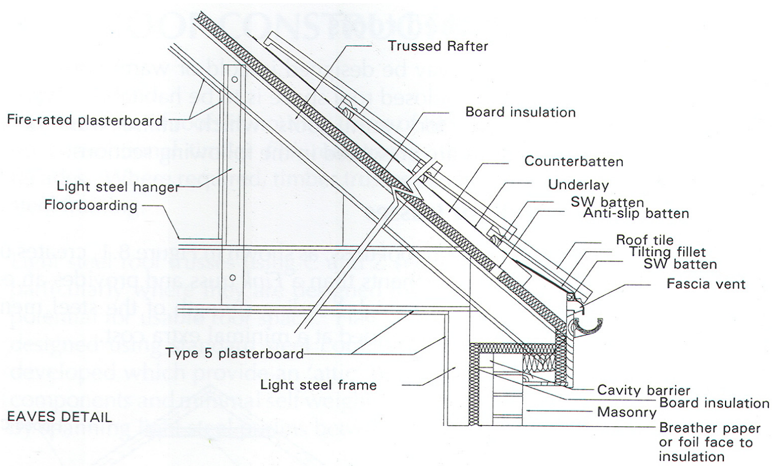


Fig. 5.50. Eave detail [28]

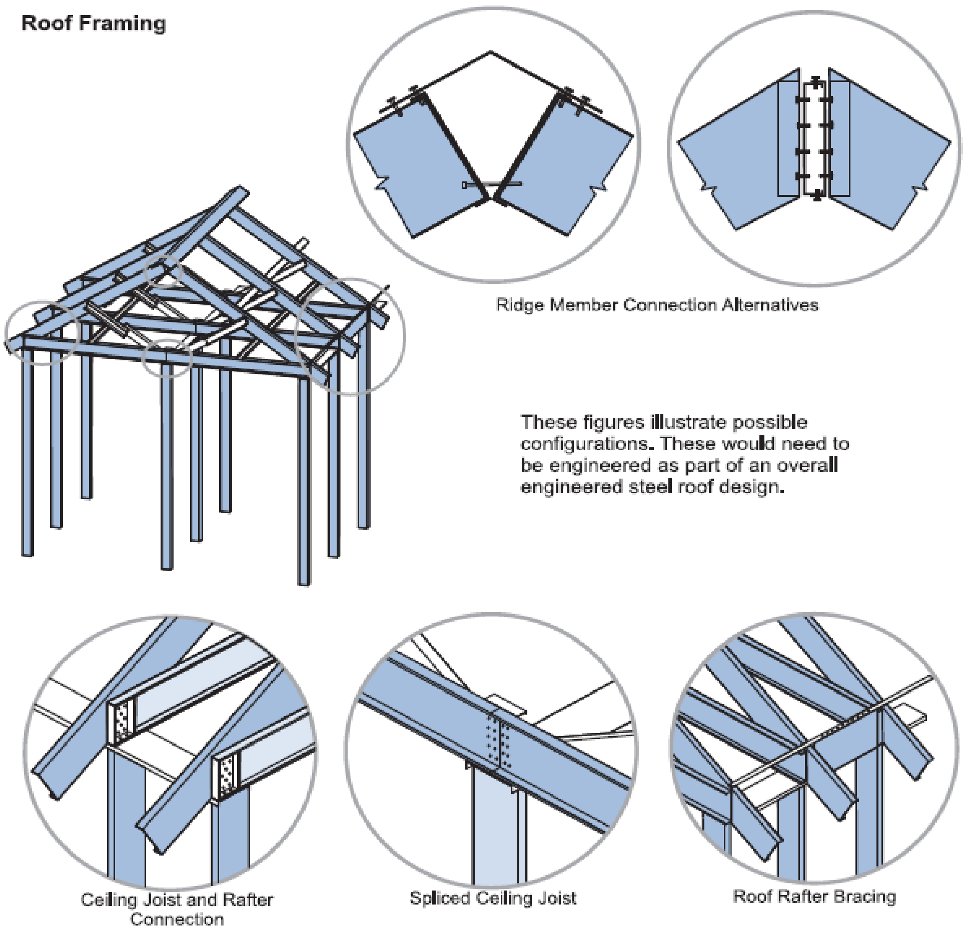


Fig. 5.51. Steel Roof Framing

Soundproofing [28]

In a CFS construction, parameters that influence soundproofing are a) the board materials and spacing, b) typology, thickness and spacing of steel elements (studs or joists), c) the typology of insulating material placed in the internal cavity and the connections and assembly typology.

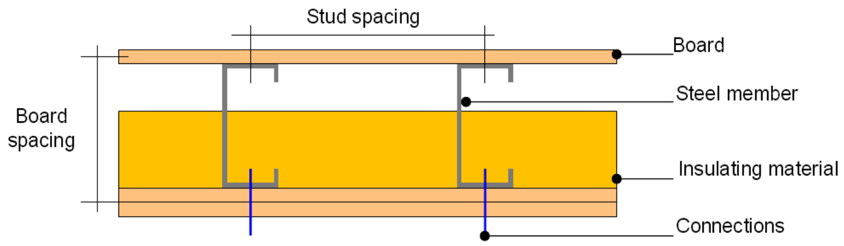


Fig. 5.52. Parameters influencing the soundproofing of wall.

In fact to obtain a good soundproofing, the sheathing should be "flexible" from an acoustic viewpoint. At this regard a 20mm thick plasterboard or wood-based panel have good properties. Moreover to obtain a better result the two boards should be separated as much as possible. Otherwise, sections that have a deep fold or thermo-purlins can be used.

Great importance has to be paid to the insulating material used to fill the internal wall cavity. In particular, when fibrous materials are used, the sound energy crossing the fibres is transformed in heat energy so that sound and thermic insulation can be reached at the same time. The sound properties are also affected by the way the boards are fixed on the steel members or on the supports.

However, attention must be paid to acoustic problems when installing metal pipes. They must not come into contact with any stud to avoid any sound transmission.

Moreover, in case of floor assembling, footsteps and impact noise have to be considered. In this case, the propagation of the footsteps through the floor can be prevented by separating the topside as much as possible from the underside. This can be obtained by using floating floors and a false ceiling. In particular, in case of false ceiling, the use of resilient bars (Fig. 8.27) between the bearing members and the plasterboard reduces connection stiffness and consequently it reduces the sound vibrations between joists and board. [28]

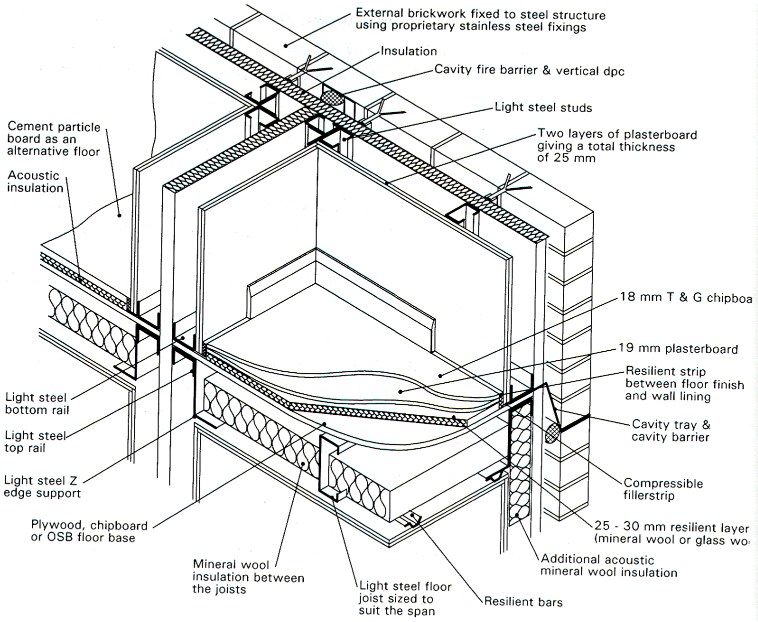


Fig. 5.53. Example of good sound insulation solution. [28]

Fire resistance

Fire design is an essential part of the design procedure of a building. Fire design methods are used to insure that a structure designed according to rules used in normal room temperatures can also withstand the additional effects induced by increasing temperature. The criterion commonly used for fire resistance of a steel structure against fire is called fire resistance-time. Structures are classified into different groups of required fire resistance time as R-15, R-30, R-60, etc. The classification is based on the type, structural system and use of the structure. Calculation models for fire design of steel structures, of class 1 and 2 cross-sections, are given in Eurocode 3, Part1-2 (ENV 1993-1-2, 2005). [28]

Steel members are incombustible (Class A, material) but they have to be protected against the effect of the high temperature during a fire. In CFS structures, walls, floors and roof are generally built using a cold-formed steel member core as the principal load-bearing system, mineral or glass wool as thermal and sound insulation and sheathing boards on the outsides. [28]

Because these elements act as separating elements between adjacent fire compartments, they should resist the spread of fire, heat and toxic fire gases into the next compartment. [28]

Each compartment of a lightweight steel structure and its location determines the category of the whole member's fire resistance category. For both walls and floor, the placing of plates, the thickness and the number of coating layers as well as the width of the insulanting are decisive for the member classification.

Thin sections of all the load-bearing members (studs, joists, rafters, etc) must be covered with anti-fire materials such as plaster, plaster-fibre, or sand limestone, which should be attached to the stud's flanges using screws at regular and sufficiently small intervals. [28]

Fire stopping is only required at vertical and horizontal intersections of spaces within an assembly where the flame spread ratings of the materials within the concealed space exceed 25. Steel framing having a flame spread rating of less than 25 does not require fire stopping. Note that if the width of the concealed space does not exceed 25 mm (1 in) then fire stopping is not required. [40]

Fire stops prevent the spread of fire through the walls and other concealed spaces by limiting the oxygen available to the fire. To achieve this requirement concealed spaces such as wall and ceiling assemblies, attics and crawlspaces must be sealed. [40]

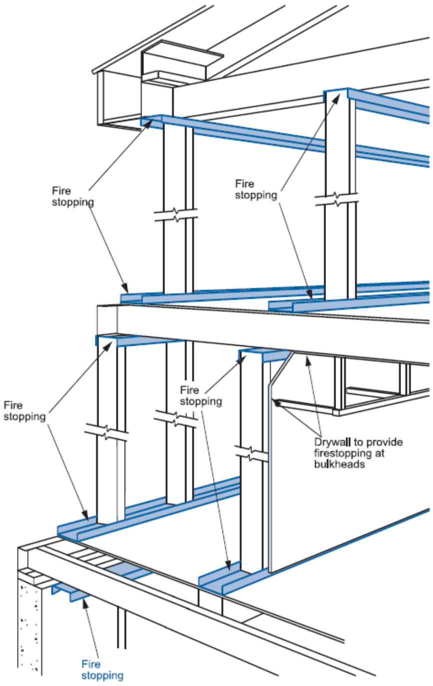
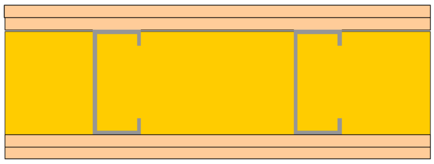
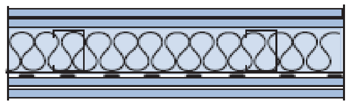
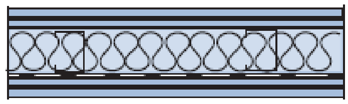
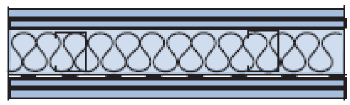
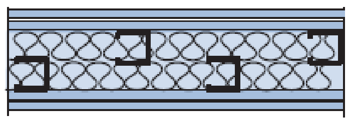
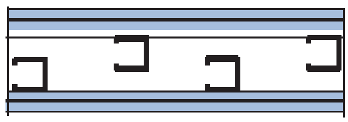
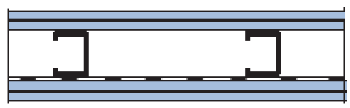
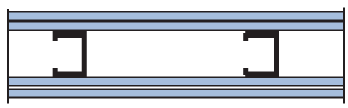


Fig. 5.54. Steel Framing as Fire Stopping[40]

Fire Resi stance		
30 min		2 x 12,5 mm Fire Proof Plasterboard 10 + 12,5 mm Gypsum Fibreboard 20 mm Fireboard
60 min		2 x 15 mm gypsum plasterboard 2 x 15 Fireboard
90 min		2 x 25 mm gypsum plasterboard 2 x 20 Fireboard 3 x 12,5 Gypsum Fibreboard

Tab. 5.4 Fire resistance duration of some wall assembly

Fire Endurance & Sound Transmission for Loadbearing Wall Assemblies			
Source	**Description**	**Fire Endurance**	**Sound Transmission Class (STC)**
NRCC A4222.2 F28	• 92 mm deep steel stud with 0.91 mm thickness spaced at 610 mm o.c. • Steel resilient channels spaced at 406 mm o.c. • 90 mm mineral fibre insulation • 2 layers of 12.7 mm Type X gypsum board on each side	 74 min	57
NRCC A4222.2 F35 F36	• 92 mm deep steel stud with 0.84 mm thickness spaced at 406 mm o.c. • Steel resilient channels spaced at 406 mm o.c. • 90 mm mineral fibre insulation • 2 layers of 12.7 mm Type X gypsum board on each side	 F35 = 68 min F36 = 63 min	55
NRCC A4222.2 F27 F31 F38	• 92 mm deep steel stud with 0.91 mm thickness spaced at 406 mm o.c. • Steel resilient channels spaced at 406 mm o.c. • Insulation (see below) • 2 layers of 12.7 mm Type X gypsum board on each side F27 - 90 mm glass fibre insulation F31 - 90 mm cellulose insulation F38 - 90 mm mineral fibre insulation	 F27 = 56 min F31 = 71 min F38 = 59 min	55 53 54
NRCC A4222.2 F26	• Double wall system with 92 mm deep x 0.91 mm thick steel spaced at 406 mm o.c. • 90 mm mineral fibre insulation • 2 layers of 12.7 mm Type X gypsum board on each side	 84 min	64
NRCC A4222.2 F30 F30R	• double wall system with 92 mm deep x 0.91 mm thick steel spaced at 406 mm o.c. • 2 layers of 12.7 mm Type X gypsum board on each side NOTE: F30R used to measure the repeatability of the results.	 F30-100 min F30R-102 min	56
NRCC A4222.2 F37	• 92 mm deep steel stud with 0.91 mm thick steel spaced at 406 mm o.c. • steel resilient channels spaced 406 mm • 2 layers of 12.7 mm Type X gypsum board on each side NOTE: F30R used to measure the repeatability of the results.	 77 min	46
NRCC A4222.2 F39	• 92 mm deep steel stud with 0.91 mm thick steel spaced at 406 mm o.c. • 2 layers of 12.7 mm Type X gypsum board on each side	 83 min	39

Tab. 5.5 Fire Endurance and Sound Transmission Tables [40]

Shear Walls

CFS buildings can be designed following an elastic design or a ductile design. In the first case, all the structural elements are designed to provide an elastic behavior under design earthquake; while in a ductile design, according to capacity design criteria, the collapse of sheathing-to-frame connections should be imposed and the other structural components should offer an adequate overstrength.

The seismic design of a CFS housing can be carried out using two different approaches: the "all steel design" and the "sheathing braced design". The first one considers only the steel members as load bearing elements without take into account the influence of sheathing panels. In this case, the introduction of X or K bracings in floors and walls are required to assure load bearing capacity. While the "sheathing braced design" takes into account the influence of panels and the systems composed by sheathing panels, fasteners and steel members can assure a good strength so that floors and walls act as in plan diaphragms. When a CFS house is designed taking into account the interaction between steel frame, sheathings and frame-to-sheathing connections, the shear walls represent the lateral force resisting system. [42]

However, the behavior of shear walls subjected to earthquake is not yet fully understood and, in recent years, an important effort has been made to clarify certain aspects related to their shear strength, stiffness and ductility. [41]

Research in USA has been focused mainly towards experimental testing of shear walls in order to produce practical racking load values. Load bearing capacities were derived both from monotonic pushover curves, envelope and stabilized envelope curves from cyclic tests. Findings of these studies suggest a conventional elastic stiffness for a wall panel at 0.4 of the ultimate load. Different frame typologies with various cladding materials were tested, studies were conducted to determine the influence of length/height ratios as well as the effect of openings. Even most of the very detailed studies avoid addressing an important aspect of shear wall behavior, e.g. the energy dissipation capacity due to cyclic characteristics. The effect of gypsum wallboard was also studied, leading to the conclusion that both strength and stiffness are increased by the presence of gypsum wallboard, some results suggesting an increase in terms of ultimate load of up to 30%, compared to the case of external sheeting only. [41]

Testing and numerical simulation have been combined in order to account for hysteretic characteristics in an attempt to provide evidence on the possible values of response modification factors (q). Vibration tests of steel-framed houses were conducted and relatively large damping ratios were found due to interior and exterior finishes. According to the tests damping ratio of 6% was accepted for seismic analysis. A maximum of 1/50 rad story drift angle limit is also suggested as acceptable during severe earthquakes. In the FE analysis stage, a steel-framed house was subjected to two levels of seismic waves. The house exhibited good performance, reaching a maximum drift of 1/300 rad. Even when minimum required wall length was provided, the maximum drift did not exceed 1/60 rad. [41]

On the same line, Gad et al. proposed a new analytical approach to evaluate the ductility parameter (R_μ), for which they suggest a value between 1.5 and 3.0 to be suitable. Their research briefly assesses inherent structural over-strength and finds it to be a very important factor as far as earthquake resistance is concerned. The quantitative evaluation of over strength is more difficult, and an empirical evaluation was performed. [41]

Serrette and co-authors (Serrette, 2006) studied experimentally, again, cold-formed wall stud panels with OSB focusing the application of adhesive to bond sheeting to framing. [41]

Experimental tests and FE modeling was employed by De Matteis to assess shear behavior of sandwich panels both in single story and multi-story buildings. A number of six monotonic and six cyclic tests were performed on full-scale sandwich panel specimens of different configurations. In the final stage of the study, dynamic modeling on panels integrated in building structures, under real earthquake records was performed. According to the conclusions diaphragm action can replace classical bracing solutions only in low-rise buildings, and in areas of low seismicity. [41]

Both experimental and numerical studies on wall studs shear panels sheeted with OSB has been realised by Landolfo et al. Physical tests have been carried out on two nominally identical wall sub-assemblages. One sub-assemblage has been tested, up to collapse, under a monotonically increasing lateral load. The second one has been instead subjected to a purposely developed cyclic loading history.

Specimens were designed according to the Prescriptive Method For Residential Cold-Formed Steel Framing. The generic wall framing, which was 2400mm long and 2500mm height, consisted of single top and bottom tracks, single intermediate studs and double back-to-back end studs, spaced 600mm on centre. The floor framing consisted of joists spaced 600mm on centre, with single span of 2000mm. The foundation was simulated by two 280x380mm (depth x width) rectangular concrete beams. The walls were connected to the foundation by intermediate shear anchors and purposely-designed steel hold-down connectors placed in correspondence of the end studs. All frame members were cold-formed, fabricated from FeE350G (S350GD+Z/ZF) hot dipped galvanized (zinc coated) grade steel (nominal yield strength fy=350MPa and nominal tensile strength ft=420MPa). Wall and floor external sheathings were made by type 3 oriented strand board (OSB/3), whereas internal sheathings of the wall were made by gypsum wallboard (GWB). [43]

All the stud shear wall sub-assemblage components (members, panels and connections) were designed according to capacity design principles, in such a way to promote the development of the full shear strength of sheathing-to-wall framing connections. For this reason, shear anchors and hold-down connectors were designed to prevent either shear failure at the base of the walls or failure due to overturning. Besides, double lipped C-sections at the ends of the walls were adopted, in order to avoid failure due to buckling in end studs. [43]

Two types of load were applied: gravity and racking loads. A gravity load of 45kN was applied on the floor of the prototype. This load was computed starting from the dead (including roof, floor and walls), snow and live loads applied to the plan area of a typical one-family one-story house, in such a way to reproduce typical values of gravity-induced axial forces in the studs. Racking loads were applied to the floor panels by means of two programmable servo-hydraulic actuators (MTS System Corporation) with the range of displacement of 500mm. The actuators' forces were transformed into a distributed load applied to the floor panels by means of a purposely-designed load transfer steel system. A sliding-hinge was placed between the actuators and the structure in order to avoid the introduction of additional vertical load components in the tested system. This testing apparatus allowed the capacity of the horizontal floor panels to transmit loads to the vertical wall panels to be checked, up to failure of the vertical stud-to-panel connections. [43]

The obtained results allow the following conclusions to be drawn:

- All the components of this structural system can be designed according to capacity design principles, imposing collapse in the vertical shear walls' connections (most ductile collapse mechanism), without significant increase of the cost. In fact, the evolution of the deformation of both tested specimens was consistent with the sheathing-to-wall framing connections failure.

- In the monotonic test the collapse mechanism was invariant during the increasing lateral displacement, whilst in the cyclic test some modifications occurred after that the peak lateral load was achieved. In fact, in the cyclic test, the wall-to-framing connections in the upper part of the wall failed before than the ones in the lower part. Consequently the panels became unzipped in the upper half of the wall inducing a distortional buckling phenomenon in the end studs. As a consequence, strength degradation in the cyclic test, after the achievement of the peak load, was stronger than the one observed during the monotonic test.

- The lateral-load response for displacements lesser than the ones corresponding to the peak strength was very similar for all tested walls, whilst significant differences were observed for larger values of the displacement. This indicates a relatively more unreliable response in the unstable branch of the behaviour.

- The horizontal diaphragm (made of a simple wood-based sheathing fastened with bugle head selfdrilling screws to horizontal cold-formed girders) can adequately transfer the horizontal loads to the of vertical shear walls, without any appreciable damage. In fact, no appreciable deformation of the OSB sheathing-to-floor framing connections was observed in both monotonic and cyclic tests. [43]

One of the largest experimental programs carried out in Europe on light-gauge steel wall panels, aiming to characterise their cyclic response has been undertaken at the "Politehnica" University of Timisoara. Both wall panels sheeted with corrugated steel sheeting and OSB has been tested. On the basis of experimental results a simplified numerical model has been proposed by authors with the aim to obtain a 3D analysis of house framing. Later, this research was completed with tests on seam and sheeting-to-framing connections. [41]

Recently, in situ ambiental vibrations tests on a real house structure under construction, have been performed by Dubina et al. in order to observe the overall response of the building in subsequent steps of erection.

The experimental program was based on six series of full scale wall tests with different cladding arrangements based on common practical solutions in housing and SIB. [41]

Their conclusions stated that cold-formed steel framing houses represents, perhaps, the best structural solution for such a type of building located in seismic areas. In terms of performance, for "fully operational" and "immediate occupancy" levels, they could be designed as "Low Dissipative Structures" corresponding according to Eurocode 8-1 taking q factor of 1.5 to 2.0, while, for "life safety" and "collapse prevention", these structures could be framed as Moderate Dissipative with a corresponding factor of 2–3. Both test results and numerical simulations sustain this assumption. [41]

Moreover, the in situ measurements provide evidence for a significant damping effect due to the finishing materials, which also contribute to resist earthquakes in the case of these constructions.

Floor Vibrations

The use of cold-formed steel as a framework for floor systems in multi-story buildings and single occupancy residences is becoming an increasingly popular alternative to traditional materials and techniques. Builders and designers have recognized that the high strength-to-weight ratio provided by the cross-section of cold-formed steel members permits lighter structures and longer spans. The longer spans and lighter structures associated with cold-formed steel floor systems can result in vibration serviceability issues if proper design considerations are not made.[61]

Floor vibration is a natural phenomenon of a floor system in response to dynamic forces, such as people walking or a washing machine's spinning, applied directly to the floor, and occur because human or mechanical activity resonates with the natural frequency of the floors. In some cases, these forces are transmitted from other floors or adjacent buildings through columns. All suspended floors vibrate to some degree regardless of the floor type, whether steel, concrete, or wood. Unfortunately, excessive floor vibration can make people feel insecure, uncomfortable, and afraid of structural failure. Such fear, of course, is usually unwarranted since the displacement and stresses induced by floor vibration are generally small in view of the design criteria for structural safety. [62]

Modern floors with large spans are light-weight constructions with a low stiffness. The low stiffness leads to low natural frequencies while the low weight to an increase in the ratio of the exciter mass to the excited mass. Therefore the assessment of the vibration of floors may become essential. Furthermore damping has an important influence on the vibration behavior of the floor. The damping properties are not only dependent on the structure, but also on the finishes and use of the premises. Thus separation walls, ceilings under the floor, free floating floors or swimming screeds affect the damping properties significantly. [63]

Most building codes use the uniform-load deflection criteria to satisfy the serviceability limit state through the maximum static deflection of a joist under a specified uniformly distributed live load. The prefabricated wood I-joist industry recommends a lower deflection than the conventional L/360 limit for live load deflection to address floor-vibration concerns. L/480 and L/600 are both common recommendations for floors constructed with I-joists, offering a generally effective solution for most floor systems. This approach has not completely eliminated floor vibration problems however, especially for long-span floors, because this criterion is based on the behavior of a single I-joist rather than the two-way action of a floor system. It is unfortunate that in current practice limiting span deflection to *L*/600 under specified uniform live load is widely misused as the sole design criterion for lightweight cold-formed steel floor framing. Knowing that *L*/600 criterion can be problematic especially for mid to long span floors, some experienced designers tend to be conservative while adopting the criterion for long span floors. [62]

The determination of potentially annoying floor motion for a proposed design requires careful consideration of the structural system, the anticipated activities, and the finished space. Art, as well as science, is required on the part of the designer. The most important parameter to be determined is the fundamental natural frequency of the floor structure. This calculation requires a careful estimate of the supported weight on an average day. Floor system damping, which depends on the components of the building systems, as well as occupancy furnishings and partitions, also must be estimated. Finally, an acceleration tolerance criterion must be selected and compared to the predicted acceleration of the floor structure.

To minimize floor vibrations, during the design process we can evaluate:

1) Changing the frequency of the floor. This can be accomplished by changing bay sizes, increasing the depth of the floor system, or in some cases just by switching the orientation of the framing.

2) Adding weight to the floor. This can be accomplished by thickening a slab, using normal weight instead of lightweight concrete, or if necessary, changing the construction type all together. Increasing the weight of the floor increases the amount of force necessary to excite floor vibrations.

3) Damping the floor. Similar to placing a hand against a ringing wind chime, damping a floor decreases the magnitude of vibrations that have been introduced.

Typically this is passively accomplished by architectural components such as ceilings, partition walls, and furniture.

Different construction types offer different levels of damping.

4) Isolating the affected area from the rest of the structure. When extreme vibration-producing situations such as running tracks, aerobic studios and dance halls are not on a slab on grade, sometimes the only way to effectively control the vibration is to provide separate framing for the area so that it is completely isolated from the rest of the structure.

5) Strong backs, or secondary beams, are an effective method of controlling floor vibration. The greater the strongback stiffness the more solid the floor will feel, even at the maximum tabulated spans. For residential floors fitted with lightweight sheet or strip flooring and a single layer of plaster board ceiling, it is recommended to specify at least one row of strongbacks near mid span, where joist spans are within 750 to1500 mm of their tabulated spans. Where joists are within 750mm of their tabulated spans, two rows of strongbacks are recommended, placed near the one-third points of the span. [64]

While any of the criteria mentioned above can be used as a design guide to provide a high percentage of acceptable or high-performance floors, the same principles are applicable to retrofitting existing floors with excessive vibration. A variety of options (or a combination of multiple options) can be taken to correct floor vibration problems, but their effectiveness may vary. It is important first to identify the cause of floor vibration and then to determine the appropriate action.

• Removal of vibrating articles: Vibrating articles in a room, such as rattling dishes, make noise and draw attention to floor vibration. In this case, the elimination of noise by removing or rearranging the articles may be sufficient to remedy the floor vibration problem.

• Soft-spot correction: Some floor vibration is caused by unsupported joist ends due to support settlement, the dimensional change of the supporting member, or inadequate attachment of floor sheathing to joists. In this case, the elimination of soft spots may be sufficient to remedy the floor vibration problem. Soft spots can often be eliminated by the use of shims, additional fasteners, or construction adhesives.

• Increase in fundamental natural frequency and reduction in vibration amplitude: If the fundamental natural frequency of the floor system is in the low frequency range, the floor vibration problem may be resolved by increasing the fundamental natural frequency. On the other hand, if the floor vibration is caused by large vibration amplitude, the floor vibration problem may be resolved by increasing the floor mass or stiffness. The following is a list of options even though some of the options may not be feasible due to the available floor space and/or economic considerations:

a) Floor joist reinforcement: the fundamental natural frequency of a floor system can be increased by increasing the floor stiffness.

b) Floor sheathing/covering: Thicker floor sheathing increases the floor stiffness across the support when properly attached (i.e., glue-nailed) to the existing floor. On the other hand, it also increases the floor mass, which tends to lower the fundamental natural frequency and the vibration amplitude. Overall, the added mass of an additional floor layer to the top of the floor joists has a positive effect on floor performance. Hardwood flooring has also been reported to improve floor performance by reducing floor vibration.

c) Ceiling-board attachment: The attachment of gypsum ceiling boards to the bottom of the floor joists has a similar effect as the attachment of an additional floor layer to the top of the floor joists. The addition of gypsum ceiling boards may also improve the fire rating of the floor system.

d) Bridging: Between-joist bridging, which is normally achieved by blocking, cross bridging, and bottom strapping, can significantly increase the floor stiffness in the across-the-joist direction. This bridging has very little effect on the fundamental natural frequency but can significantly reduce the vibration amplitude if it is achieved with a continuous bottom strap.

e) Span reduction: If possible, a reduction in the floor span by adding a support can drastically reduce the floor vibration problem. [64]

Construction of Light Gauge Steel Framed Structures [39]

In principle, the production of housing components can be done according to three different production methods: on-site production, field fabrication, and fixed industries.

On-site construction is the traditional building method that has dominated housing production so far. The difference between traditional building and on-site construction with Light Gauge Steel Framing is that included materials are delivered code marked and size adjusted to the work site. Made-to-order steel studs are delivered in cutting lengths with tolerances of 0 - 2 mm and with pre-punched holes for service installations. No on-site processing is required. Joining of the framework is done on-site and usually self-drilling screws are used. Gypsum boards and mineral wool can also be delivered size adjusted to the work site.

Advantages of on-site construction:

- Investment in a factory space not required.
- Construction workers are accustomed to the work method.
- It is possible to implement late decisions and changes.
- Aids and tools have been developed and are adjusted according to production in the field.
- Employment of a company's own work force.

Disadvantages of on-site construction:

- Longer construction time.
- Storage areas for materials at the work site are necessary.
- Materials and building parts are exposed to wind

On-site production takes more time and the building components are then exposed to the weather for a longer period. The choice of production method is very dependent on what resources are available. Onsite construction has a greater need for manpower, but this can be costly for complicated construction of individual objects where prefabrication is not profitable.

In the case of the field fabrication, wall elements, floor elements, and roof trusses are manufactured in a temporary facility for the construction project or in a separate area of the work site. The degree of prefabrication can vary from a prefabricated framework to finished or partially finished units with windows, doors, and facade material. The field factory makes it possible to use more industrialised fastening techniques, such as clinch riveting that requires tools that are heavy and have to be permanently installed.

Advantages with a field factory:

- Units are produced under controlled conditions.
- Opportunity to use industrial fastening methods.
- Increased productivity compared to on-site construction.
- Major investments in facilities and production equipment can be avoided.
- Efficient utilisation of resources.

- Good working environment and clean work site.
- Can be combined with on-site construction.

Disadvantages of a field factory:

- Junctions between building components must be done carefully.
- Damage to materials during handling.
- Elements are exposed to weather before the facade cladding has been installed.
- A crane is required.

The fixed industry produces prefabricated units, which can be wall or floor elements, framework, roof trusses, but also finished volume modules and special units such as service panels, bathroom modules, and walls for building services and elevator shafts. A fixed industry requires more investments compared to the other two production methods, but can provide a number of advantages:

- High degree of precision and high quality.
- Higher productivity with short construction time.
- Reduced waste.
- The need for storage surfaces at the construction site is drastically reduced.

Disadvantages of a fixed industry:

- Delivery times.
- Price fluctuations.
- Damage during handling.
- Careful project planning and early decisions are required.

A fixed industry may appear to result in more transports since the materials are transported to the industry and from there on to the construction site where assembly takes place, but larger production volumes also means that transport can be utilised efficiently.

There are, of course, combinations of these three building methods. The construction system of Light Gauge Steel Framing is open to all these production methods and variants. For each individual housing project, an evaluation must be done of what degree of prefabrication would produce optimum economics.

One of the foremost advantages of Light Gauge Steel Framing is that of dry construction, significantly reducing the risk of moisture problems.

Steel profiles are manufactured to tight tolerances; likewise, gypsum wallboard and mineral wool are also manufactured to precise dimensions, a prerequisite for industrial construction. Controlled industrial construction of wall and floor units and rapid assembly also brings with it high quality. Steel, gypsum wallboard, and mineral wool have a closed life cycle and are 100 % recyclable, a prerequisite for future construction.

Steel profiles are hot dip galvanised with 275 gram of zinc per square meter, corresponding to a zinc thickness of 20 μm on each side. Hot dip galvanising is sufficient to protect the steel profiles against corrosion during the entire life of a building, if it was constructed in the correct manner. The most severe effects of corrosion on the steel occur during transport and storage outdoors. When making holes in hot dip galvanised steel framing members, normally no treatment is needed afterwards since the zinc layer has a healing effect, i.e. it transfers to unprotected surfaces.

Hot dip galvanising is sufficient to protect the steel profiles against corrosion during the life of a building. The service life of hot dip galvanised steel studs was studied by British Steel and others. The loss in zinc weight will be around 0.1 g per m^2 per year indoors. A similar study was also carried out for steel floors above crawl spaces with plastic sheeting on the ground. Results showed that a zinc weight of 275 g/m^2 is sufficient to provide a durability of around 100 years.

Design Method for Mixed Steel-Wood Structural Systems [44]

Hybrid construction combines the structural and architectural advantages of components made from different materials. In hybrid construction, various materials may work independently or act together homogeneously, but are always better than a single material.

Even though, steel and wood are two very different materials by combing them in a hybrid structure one can take advantage of the inherent benefits of each material and overcome their limitations. In-depth understanding of the properties of each material is essential for designing a hybrid structural system. Engineers and architect should remember the strengths of each material and know in what context each of them work best. Steel excels in tension while wood reacts much better to compression.

Combining steel and wood will increase the seismic performance of the structure. Wood has a high strength to weight ratio therefore wood buildings tend to be lighter than other building types. Lightness is an advantage in an earthquake. Since forces in an earthquake are proportional to the weight of the structure, lightweight wood-frame buildings that are properly designed and built can be expected to perform very well in earthquakes. On the other hand, steel will add ductility to the timber structure. Ductility is the ability of the structure to yield and to deform without collapse. It is desirable for a building to have some flexing capability when subjected to the sudden loads of an earthquake because the flexing allows the building to dissipate energy.

Wood is environmentally friendly due to its reduced carbon footprint. In this era of global warming, sustainable development strategies are not only essential, but are increasingly mandated by most governments. Wood, as the most sustainable, natural, and renewable building material, needs to be more widely used in the building industry. However, products such as glulam (glued laminated timber) and structural composite lumber are considered engineered products because of the manufacturing process. While the gluing and lamination increases the strength and reduces the moisture content of the wood, it makes the products unsuitable for recycling and, as with many wood products, generates up to 30 per cent wasted wood, which counters some of the positive marks for green building that wood receives for being a renewable resource. On the other hand, steel has high level of recycle content. Therefore, combining steel and wood would result in increase in sustainability.

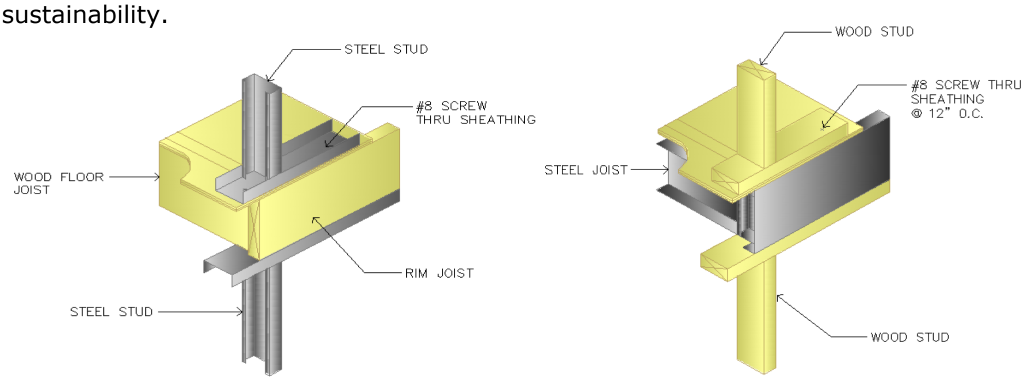


Fig. 5.55. Mixed steel-wood framed structure

In most countries around the world, building codes have height and area limitations on wood construction due to fire safety considerations. But there is no limitation if wood is used with a non-combustible material such as steel. Although wood is combustible, but buildings constructed with large structural timbers have excellent fire-resistive qualities. Fire resistance is the length of time a structural member can support its load before collapsing. Steel is a non-combustible material, but the mechanical properties of structural steel are affected by heat. However, in fire, timber members char on faces exposed to fire but still retain strength and stiffness by virtue of the much cooler core within the charred surfaces and thus their performance is predictable and collapse is unlikely. Hence, hybrid steel and timber structures perform better in fire.

Pairing steel and wood in a single project can lead to unique assemblies of aesthetically pleasing hybrid structures. The warmth of wood can add a welcoming touch to an all-steel building. The strength of steel lessens the bulk and provides an economy of structure that would not be possible with an all-wood design. For instance, steel could more elegantly handle the concentration of forces at the columns' bases, noting that the comparable wood section might have been as much as 25 to 50 percent deeper.

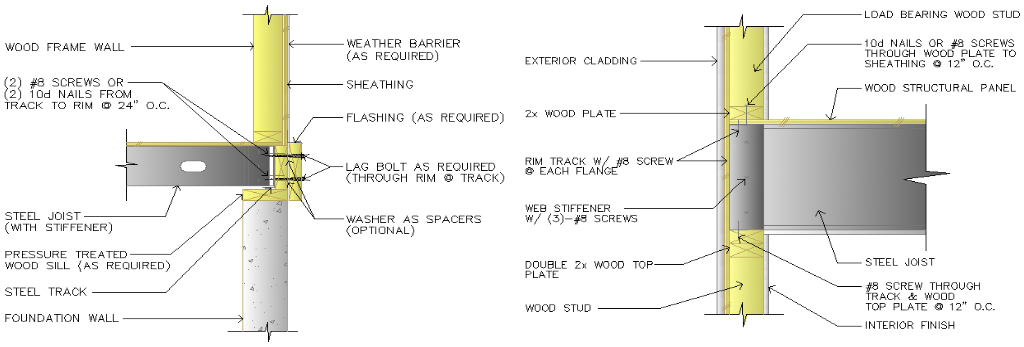


Fig. 5.56. Mixed steel-wood framed structure

Moreover, combining steel with wood would enhance the durability of an all timber structure. Steel is a manufactured commodity, product quality is assured and will have no knots, twists, splits or other defects often associated with wood. Unlike wood, steel is resistant to termites, creeping, cracks, splitting and rotting, mould and mildew.

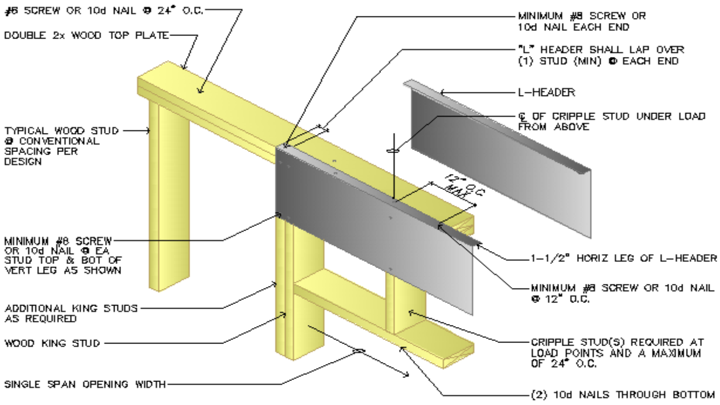


Fig. 5.57.Mixed wood-steel lintel

Finally, many case studies suggest that hybrid construction is cost effective as it combines the benefits to be derived from using components of different materials. The technique requires the cooperation of architects, consulting engineers, manufacturers, suppliers and contractors.

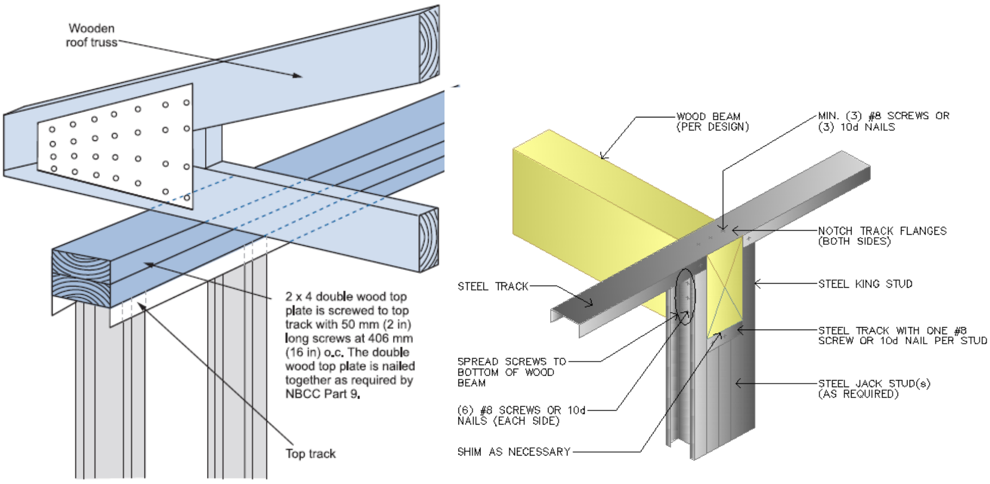


Fig. 5.58. Mixed steel-wood frame

Because of their different properties, connections between wood and steel can be difficult. The big problem from a structural point of view is the different expansion/contraction coefficients when you have dissimilar materials, especially on a column-beam- wall type interface. A temperature differential cause steel to expand and contract but has little effect on wood. In conditions of repeated stress and changing temperatures, recent experimental evidence has shown that steel joints exhibit a distinct change in their moment–rotation response under increasing temperature. They exhibit a pronounced reduction of strength and stiffness. Coupled with the thermal elongation of steel, this results in steel joints quickly reaching yield under fire conditions, even at constant mechanical loading.


Fig. 5.59. DM. House - Mixed Steel-Wood Structural System

Changes in humidity, which have little effect on steel, can cause wood to shrink and permanently change its dimensions. In some cases, slotted holes in the steel can allow for some movement. Because it is important to limit the restraint that the steel connecting elements impose, a bolted steel connection should not span the full depth of a wood element.

Fig.5.60. B.House
Mixed Steel-Wood Structural System

P. House
Mixed Steel-Wood Envelope System

There are other issues where wood and steel come into contact as well. Steel needs to be protected, by being galvanized or with a specific paint system, in order to resist the humidity changes in the wood. It also helps to use dry wood instead of green wood at the interface, if possible, because it moves less over time.

There are three ways hybridization of steel and timber that can be used in construction: structure, system and material. "Structure" is the major type of hybrid construction. In structure hybridization a structure is simply constructed using both timber and steel members. "System" is another type of hybridization where timber and steel are assembled to create a structural system. "Material" hybridization exists when a mix of steel and timber is employed within a structural element. This is similar to a composite construction where two different materials are bound together so that they act together as a single unit from a structural point of view. Material hybridization is also used in house building but to a lesser extent.

5.5. Building Envelope Design and Indoor Environmental Quality Requirements

The building envelope is the physical separator between the interior and the exterior environments of a building. It serves as the outer shell to help maintain the indoor environment (together with the mechanical conditioning systems) and facilitate its climate control.

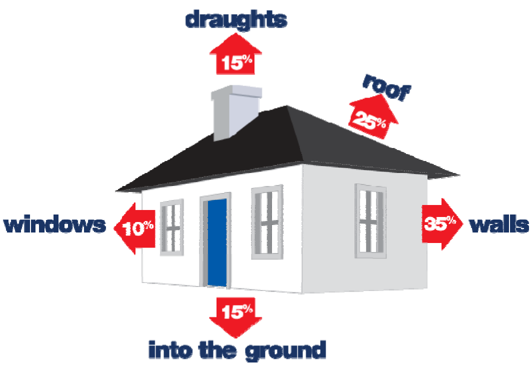
The first building envelope that protected humans from the elements was probably a cave that provided a degree of privacy and security. The earliest building envelopes were dome-shaped structures that combined wall and roof. At an early stage, however, the two dominant forms of envelope evolved, depending on climate and available materials: the timber frame and the masonry wall. Early shelters in the warm climates of Africa and Asia used timber or bamboo frames clad with leaves or woven textiles. In other regions and climates heavier indigenous materials such as stone, rock and clay baked by the sun were used to provide more permanent shelter and protection from the heat and cold. [46]

The building envelopes should be energy-positive, adaptable, affordable, environmental, healthy, intelligent and durable. The envelope is essential in ensuring the comfort and energy savings of the system taken as a whole. All envelopes have to address some of the following problems:

- To provide an exterior layer which has to balance the needs of protection from the elements, visual value and economics;
- The thermal insulation has to be compatible with the exterior layers and mechanically fastened to the structure; optionally, there could be a cavity space for ventilation;
- The interior components of the envelope containing the finishing surfaces can be permeable or not. The consistency of this last layer has a great influence on the indoor air quality. The trend today is to use gypsum board and vapor barrier on studs.

Thermal insulation

Fig. 5.61. Heat loss through building components



Insulation is defined as a material or combination of materials, which retard the flow of heat. The materials can be adapted to any size, shape or surface. A variety of finishes are used to protect the insulation from mechanical and environmental damage, and to enhance appearance.

Thermal insulation is specified to control three components of heat transmittance through the building fabric, thereby lowering heating and cooling costs while minimizing the potential of condensation on or within building components:

- Conduction of heat through building fabric
- Convection via air movement
- Radiant transmission, typically through glass but also through other elements of building fabric,

Insulation acts to increase the thermal resistance of particular elements of the building (i.e. reduce thermal conductivity), thus slowing the rate of heat transmittance. Thermal resistance is expressed as an 'R-value' where the higher the R-value the higher the thermal resistance. Insulating materials with higher R-values reduce the rate of heat loss (or gain in summer) from a building. This reduces the need to provide supplementary energy for either heating or cooling and improves the ability to maintain a comfortable temperature range for humans (typically 18-24°C). In general the benefits of insulation are greatest the more that outside temperatures diverge from the temperature range for human comfort. [47]

The rate of heat transmittance is inversely proportional to the R-value. That means that for each building element, increasing levels of insulation displays strong diminishing returns effects. An example is shown in Figure 5.63 where the heat flow through an uninsulated wall is compared with successively adding increments of insulation with an effective R-value of 1.0 m^2 K/W. The uninsulated wall is assumed to have an R-value of 0.4 m^2 K/W, while the particular conditions chosen assume a heat flow through the uninsulated wall of 1000 Watts. Adding the first increment of insulation with R1.0 reduces the heat flow by approximately 710W (71%); adding a further increment reduces heat flow by only about another 120W (12%). When the insulation is increased from R3.0 to R4.0 the heat flow is reduced by only about 30W (3%). Therefore, determining "optimum" levels of insulation involves assessing marginal cost effectiveness of each increment of insulation, for each element of the building. [47]

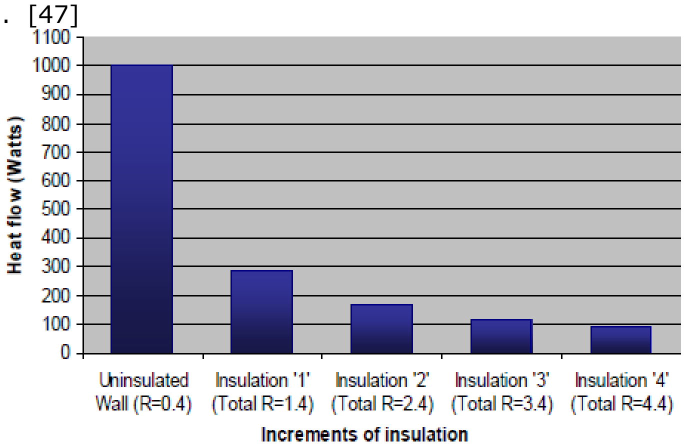


Fig. 5.62. Diminishing returns effects from adding increments of wall insulation [47]

There are a wide range of factors that could be considered when determining the appropriate insulation solution. While the target for an absolute reduction in energy consumption and carbon emissions should be the main driver, there are other factors which should be considered. These include:

- Effect on building design, such as the impact of external wall thickness on layouts, net floor area and light penetration through window reveals.
- A balance between heavyweight and lightweight construction, including considerations related to exposed thermal mass.
- Performance in use and longevity.
- Build-ability and the risk of on-site work not meeting the required design standards.

- Sustainability implications of the production process including sourcing of raw materials, ozone depletion, embodied energy and eventual disposal.

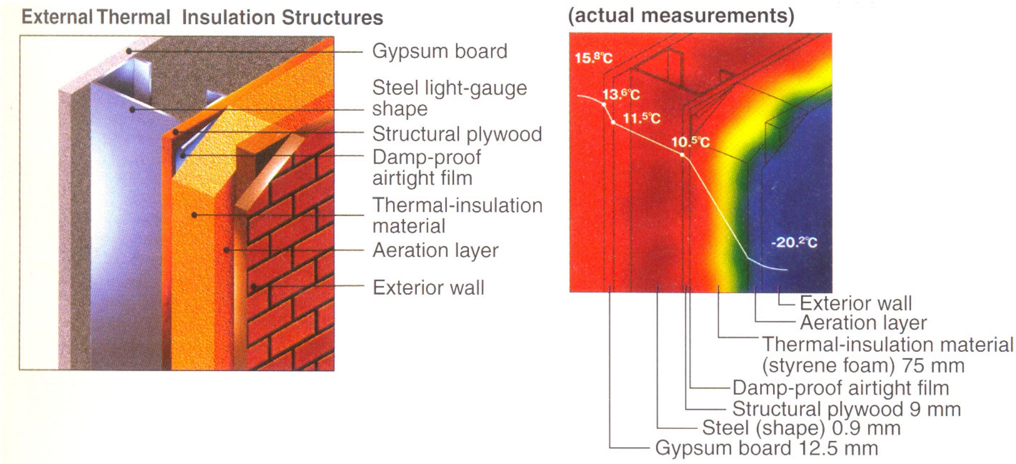


Fig. 5.63. Thermal performance of an insulated stud wall assembly

Insulation should be viewed as an assembly rather than a material, since it is constructed in many different forms for various applications. Heat loss from a building is determined by the sum of losses from each element of the building envelope. Because the loss from each element is proportional to its area, and since diminishing returns principles apply to each building element, it is not possible to substitute higher insulation values in one element (say ceilings) to compensate for no insulation in another (say walls). However there is the ability for limited trade-offs as long as each element has some basic level of insulation. [47]

There are three primary families of insulating products distinguished by the sourcing of their raw materials:

Mineral fibre-based products

The product family includes mineral fibre and glass fibre.

Mineral-based products are available in batts, rolls and loose. This makes them suitable for most applications in off-site and in situ construction. Mineral-based products have an open structure and are air and vapour permeable. As a result, site detailing of vapour and radiant barriers, such as foil backing, are important in ensuring long-term performance.

Mineral products typically have a higher rate of thermal conductivity than plastics- based products, requiring typically 50% thicker insulation to achieve the equivalent performance. U-values of 0.2W/m²K can be achieved with a mineral wool thickness of 125mm in a standard cavity wall and 165mm in a timber frame. Reducing U-values to 0.1W/m²K requires between 300 and 350mm of insulation overall – equivalent to a total section thickness of just over 500mm – a significant potential loss of floor area. [47]

Mineral and glass wool products are sourced from recycled waste, albeit that chemical binding agents are required to form rigid sheets and insulation batts. Mineral fibre insulation can be reused if removed in a suitable condition. There are no health issues associated with the disposal of mineral fibre by either incineration or landfill.

Mineral cellular products

Mineral cellular products are available in blankets, batts and boards. Cellular glass and vermiculite have a higher thermal conductivity than mineral fibre products, requiring an additional 30% thickness to achieve an equivalent insulation performance. Cellular glass is dimensionally stable and impervious to air and water vapour movement, making it suitable for use in exposed conditions. Vermiculite can be used as loose fill. Their thermal conductivity is stable in the long term.

Cellular products are formed using recycled waste product such as glass, together with an aerating agent. Mineral cellular products can be recycled as building aggregates. [47]

Plastic cellular products

Plastics products range from extruded and expanded polystyrene to phenolic foamboards and are available as foam, rigid sheet and loose fill.

The thermal conductivity of foam-based products is very low, enabling high levels of performance to be achieved using a significantly thinner section. The differential increases as required U-values get lower, making plastics products particularly suitable for super-insulation applications. They are dimensionally stable and are not affected by water ingress, rot or vermin attack.

Plastics products are created mostly from oil-based raw materials. The production of plastic insulation has been associated with the use of ozone-depleting agents such as HCFCs. Hydrofluorocarbons (HFCs) are now used for production in Europe. They have no effect on ozone, but are still greenhouse gases. Over time, production is switching to the use of neutral hydrocarbons or CO^2 as blowing agents. Some plastic insulants can be difficult to recycle and dispose of. [47]

Plant and animal-sourced cellular and fibrous products

Plant and animal products are sourced from renewable raw materials. Their production typically has a low embodied energy and low impact on the environment (Rawlinson, 2006), although because for a given R-value the weight of material needed will vary from one material to another, it is important to compare embodied energy on an R-value basis rather than simply on weight (a point that has often been overlooked). A large proportion of both glasswool and wool products are sourced from recycled waste. Chemical binding agents are required to form insulation segments and blankets. [47]

Cellulose and wool-based insulants require chemical treatment to protect them from fire, rot and rodent infestation. The long-term performance of the chemical treatments is potentially vulnerable to degradation because of the presence of moisture. The thermal performance of wool and cellulose are more susceptible to degradation by moisture than glasswool and polyester because they will absorb a greater quantity of moisture. In the past claims have been made that the cyclic absorption and desorption of moisture in wool insulation provides additional thermal resistance. Whilst it has been shown to occur the research also showed that the actual impact was negligible relative to the benefits of simply using thicker or denser insulation. [47]

Cellulose fibre begins to settle the moment it is installed so it is important that the settling rate is determined and allowed for when the material is installed. This means the initial thermal resistance at installation must always be greater than the required or claimed performance. Settling is 10% or more and will depend on the density it is installed at. [47]

The performance of fibrous insulation materials reduces if they are compacted. One source of compaction is leaks which allow sufficient water ingress to saturate the insulation. Even when the insulation becomes dry again after the source of water is eliminated the material may not re-loft to its original thickness. Polyester insulation appears to be able to re-loft after saturation better than wool or glasswool but it will depend on factors such as density and fibre diameter. In general, denser and coarser fibres are more robust, but these factors generally decrease insulation performance so a trade-off must be made. [47]

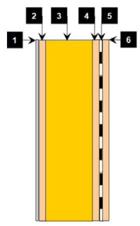
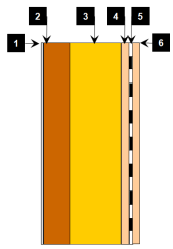
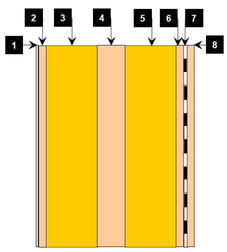
Basic material	Product type	Applic-ation	New or Retrofit	Form	Durability/ longevity	End of life/ disposal	Sustainability	Insulation value	Comment/issues
Fibre	Glasswool	Ceilings, Walls, Floors	New, Retrofit	Segment, blanket (sometimes foil-backed)	Early product prone to slumpage and deterioration. Current product more slump resistant. Loses insulation properties if wet	Potentially recyclable to form new product	NZ sourced, and overseas sourced from common materials; may contain high proportion of recycled fibre depending on particular manufacturing plant	~R2.5 per 100mm for low density product; denser products (such as specialist wall insulation) have higher R-values per 100mm	Some variation in product e.g. proportion of recycled product
	Wool	Ceilings, Walls, Floors	New, Retrofit	Segment, blanket (sometimes foil-backed), loose fill, often in blends with polyester	Chemical treatment protects from fire, rot and pests; also for slump resistance in segments/blankets. Loose-fill prone to slumpage over long term	Potentially recyclable depending on blended content	NZ-sourced, renewable product; may contain high proportion of recycled fibre;	~R1.8-2.3 per 100mm in blanket form;	Blended content can lead to variation in product quality Long term durability of R-value unclear
	Polyester	Ceiling, Walls, Floors	New, Retrofit	Segment, blanket, sometimes available in wool blends	Stable, long-life product. Prone to compression damage in storage which may compromise R-value	Potentially recyclable	Petrochemical based but low mass product	R1.8-2.0 per 100mm for low density product; denser product available	
	Cellulose	Ceilings, Walls	Mostly Retrofit	Blown loose fill	Chemical treatment protects from fire, rot and pests; prone to slumpage and moisture retention over time, rendering it less effective	Not recyclable because of chemical content	NZ-sourced, renewable product; may contain high proportion of recycled fibre;	~R2.5 per 100mm but may decline to half that over time	Lower initial cost compared with other fibre products, but expected shorter life. May be useful product for retrofit insulating ceilings with poor accessibility
	Straw	Walls	New	Compressed bale	Generally stable so long as low moisture content initially, and wall linings protect from moisture ingress	Likely to be biodegradable at end of building life	NZ-sourced, renewable product	Typically R3-R4 for 400mm bale width in straw bale houses	Durability extremely sensitive to moisture – protection from moisture ingress at construction especially critical.
Cellular	Expanded polystyrene	Ceiling, Walls, Floors	New, Retrofit (mainly for floors)	Sheets, beads (less common); sheets sometimes embedded into structural elements	Stable, long-life product, especially when fully enclosed; vulnerable to damage if exposed	Potentially recyclable; earlier products may contain CFCs so will require special disposal	Synthetic, petrochemical based but low mass product; often produced with high recycled content	R2.5-3.0 per 100mm	Some shrinkage can occur, and may affect the integrity of some friction fit installations e.g. underfloors
	Polymer	Ceiling, Floors	New, Retrofit	Rolls, generally foil-backed	Assumed stable, long-live product	Unlikely to be recyclable	Synthetic product	Unclear – supplier reports state up to R3.2 but unlikely to achieve this in practice	Independent information on product R-values needed for applications in New Zealand houses

Tab. 5.6 Available types of insulation

Foils are used largely as a reflectance barrier to reduce radiative heat flows. The most common application is under floors, both in new houses with suspended floors and in retrofitting into existing houses. In this situation the performance of the foil is reliant on the creation of a still air insulating layer to minimize convective losses. It therefore requires that the still air layer is protected to ensure it is not, or doesn't become, naturally ventilated. Although underfloor foil may help to prevent moisture intrusion through the floor, it is not a substitute for polyethylene ground cover. This will be the case even when the joins are taped. [47]

The most commonly used material to date has been simple double sided metallic (aluminium) foil with high reflectance, but a range of alternative forms of foil-backed products are now becoming available. These include relatively simple variations where foil is bonded to conventional bulk fibrous insulation, and new formulations where a reflective layer is bonded into laminated sheets with polypropylene, or other cellular polymer sheets. [47]

Tab. 5.7 Transmittance value of some common wall assembly [Lsk, 2005].

Wall section		mm	U-value	Fire resistance
	1. External layer (reinforced, mineral) 2. Plaster board 3. Mineral wool&stud 4. Plasterboard 5.Vapor barrier 6. Plasterboard	10 15 150 12,5 - 12,5	0,48	30min
	1. External layer (reinforced, mineral) 2. Wooden soft fibreboard 3. Mineral wool&stud 4. Plasterboard 5.Vapor barrier 6. Plasterboard	10 80 100 12,5 - 12,5	0,29	30min
	1. External layer (reinforced, mineral) 2. Plaster board 3. Mineral wool&stud 4. Mineral wool 5. Mineral wool&stud 6. Plasterboard 7.Vapor barrier 8. Plasterboard	10 15 100 50 100 12,5 - 12,5	0,18	30min

Due to the complexities of modern buildings, simply specifying insulation types (or even particular products) is not enough to ensure durable and reliable performance. In addition to the material's physical properties, other design elements of the insulation are also critical:

- its location within walls and roofs;

• its sequencing with respect to other layers in the assembly (especially air barriers and vapor retarders);

• its interface with surrounding or penetrating materials; and

• the continuity within and between insulating components. [48]

Regardless of the system/wall assembly, the envelope has to, as much as possible, provide a uniform "wrapping" of the steel structure in order to avoid and/or control thermal bridging. This aspect is most important since all condensation problems start from here.

As with other transport phenomena, heat naturally follows the path of least resistance. When a highly conductive material like steel is placed in parallel with an insulating material, the majority of the heat transfer occurs through the metal, which offers less resistance to heat flow. The steel 'bridges' across the insulation, creating an easier path for heat to flow. [48]

A thermal bridge, also called a cold bridge, is a fundamental of heat transfer where a penetration of the insulation layer by a highly conductive or non-insulating material takes place in the separation between the interior (or conditioned space) and exterior environments of a building assembly (also known as the building enclosure, building envelope, or thermal envelope). [48]

Thermal bridging is created when materials that are poor thermal insulators come into contact, allowing heat to flow through the path of least thermal resistance (R-value or a materials effectiveness in resisting the conduction of heat) created, although nearby layers of material separated by airspace allow little heat transfer.[48]

Insulation around a bridge is of little help in preventing heat loss or gain due to thermal bridging; the bridging has to be eliminated, rebuilt with a reduced cross-section or with materials that have better insulating properties, or with a section of material with low thermal conductivity installed between metal components to retard the passage of heat through a wall or window assembly, called a thermal break. [48]

One of the most common thermal bridging problems occurs in framed exterior walls. Light-gauge steel framing is extremely popular due to its low weight, high strength, and ease of erection in the field. However, steel is also a highly conductive material, with a thermal conductivity more than 1000 times higher than typical building insulation. [48]

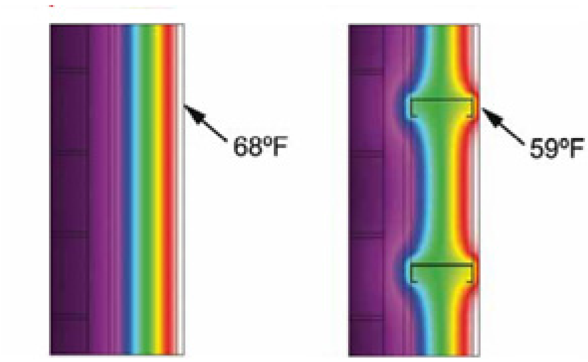


Fig. 5.64. Thermal Bridging through Light Gauge Steel Studs [48]

In sheathed walls, glass fiber batt insulation is commonly placed between steel studs spaced. These studs create ideal heat flow paths through the insulation. If one were to ignore the studs, the U-value of a typical brick veneer/stud wall assembly (assuming R-19 glass fiber batt insulation) is approximately 0.25 W/(m^2K). When one considers the same wall and includes the effects of the steel studs, the U-value is approximately 0.5 W/(m^2K). The addition of steel studs results in a 50-percent decrease in the overall thermal resistance of the wall. [48]

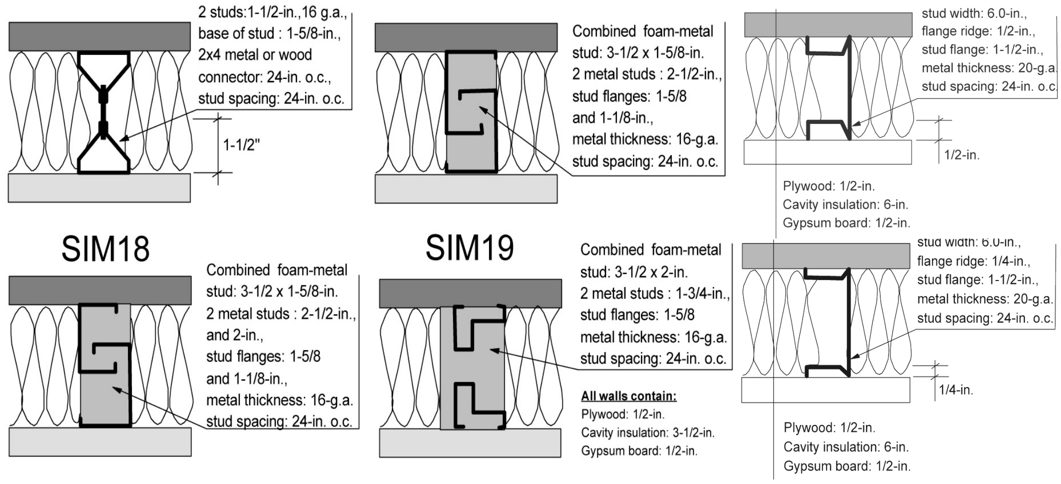


Fig. 5.65. Light Gauge Steel Studs Designed to Reduce Thermal Bridging

If 50 x 150-mm wood studs are used in place of steel studs, the resulting reduction in thermal resistance is approximately 15 to 20 percent due to the relatively low thermal conductivity of the wood.

The most obvious problem related to thermal bridging through steel studs is increased heat loss (or gain, depending on the season). If the effect of the studs is not taken into account by the mechanical engineer, heating and cooling systems can end up significantly undersized.

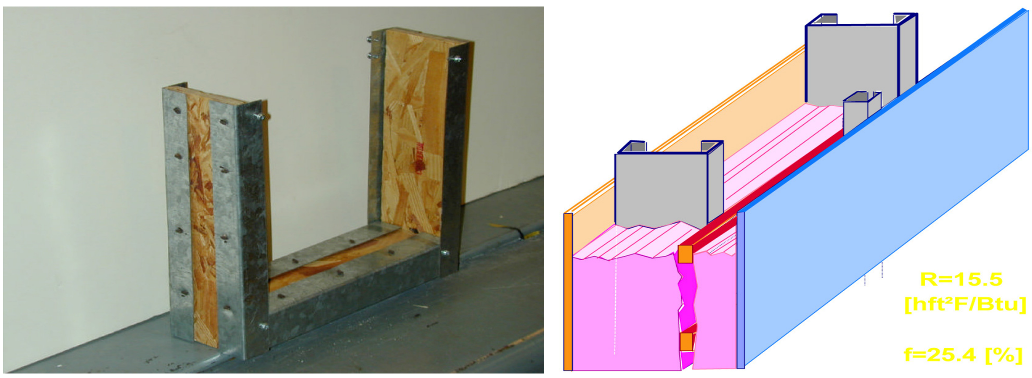


Fig. 5.66. Methods for reducing thermal bridging

A more subtle problem, often referred to as 'ghosting,' can occur when localized low temperatures at the studs lead to condensation and/or deposition of dust particles on the wall surface from the interior air. Ghosting is more of a concern in buildings with high interior humidity levels or unusual concentrations of airborne contaminants, but it can occur in residential buildings under certain conditions. [48]

Humidity Control

Two basic types of moisture problems may exist in the home, insufficient or excess moisture. Insufficient moisture in the air can cause dry nasal passages, increased respiratory problems and excessive static electricity in clothing and carpets. Humidifiers or vaporizers will add moisture to the air when it's too dry. [49]

Excessive moisture in the air is a far more complex problem, but one that can be solved. Excessive humidity can cause a number of undesirable conditions--some obvious, but others not always evident or visible. Some indications of excessive moisture in the home are:

- Condensation, frost or ice on the inside surface of windows.
- Damp spots on ceilings or inner surfaces of exterior walls.
- Mould or mildew growth on walls and ceilings.
- Peeling or blistering of exterior paint.
- Ice or frost on the underside of roof sheathing in the attic space.
- Moisture on basement walls and floors.
- Sweating water pipes. [48]

Moisture problems in the building envelope are the result of water or water vapour migration from the inside or outside of the building into the envelope and accumulating on or inside the building envelope.

This migration generally takes place by any of the following four moisture transport mechanisms:

- Liquid flow by gravity or air pressure differences
- Capillary suction of liquid water in porous building materials
- Movement of water vapour by air movement
- Water vapour diffusion [50]

Fig. 5.67. Effects of excessive humidity

Normal household activities such as cooking, cleaning, bathing, washing clothes and dishes, drying clothes, breathing and perspiring can raise the humidity level too high. It has been estimated that the typical family of four converts three gallons of water into water vapour per day. It takes only four to six pints of water to raise the relative humidity of a 1,000 sq. ft. house from 15 to 60 percent. To avoid the problems of excess moisture it is necessary to limit or control the amount of water vapour in the house. This can be accomplished by modifying lifestyle habits and by using mechanical means such as exhaust fans, dehumidifiers, and air-to-air heat exchangers. [49]

Four factors dictate whether a home's moisture balance will become uneven enough to cause problems. The four balancing factors are source strength, temperature, moisture transfer rate and circulation-ventilation rate. In a home without moisture problems these forces are typically in balance. These factors are critical to understanding and solving home moisture problems.

SOURCE STRENGTH is often the most important factor because moisture problems cannot exist without sources of moisture. Controlling the source of a moisture problem is usually the most productive and cost-effective approach to solving the problem. Examples of indoor source reduction solutions include: fixing plumbing leaks, reducing moisture from domestic activities and reducing the use of a humidifier. Outdoor source reduction solutions include improving drainage, fixing leaks and being aware of soaking and puddling from lawn sprinklers. If sources can't be reasonably or affordably controlled, then it is time to try another route.

TEMPERATURE differences which promote unwanted condensation should be remedied. Temperature solutions include: bringing warm air to cold surfaces through improved heating patterns, insulating surfaces against cold temperatures, installing vapour barriers and simply being aware of temperature differences and not allowing warm moist air to contact cooler surfaces such as walls, basements or crawl spaces.

The *MOISTURE TRANSFER* rate in a home can be altered in several ways. These moisture transfer solutions include: sealing air leaks from inside the home, weatherizing before insulating, using vapour barriers in crawl space areas, stopping all exterior leaks and puddling of water and increasing the moisture resistance of exterior wood.

The *CIRCULATION-VENTILATION* rate of a home can be adjusted to help solve moisture problems. Venting the moisture out of enclosed areas is the usual solution. Increased circulation and ventilation are also back-up options when internal moisture sources cannot be reduced sufficiently. Circulation and ventilation solutions include: installing properly-sized vents located to promote circulation, using materials that can breathe on the cool side of moisture resistant surfaces, using spot ventilation in high moisture areas such as baths and kitchens, using small efficient fans to move internal air through a house or using air-to-air heat exchangers to reduce moisture but keep heat or coolness. [49]

The previous discussion points toward two major approaches to moisture control in the building envelope: constructing with a high tolerance for moisture and operating the building to limit the moisture load on the building envelope. [50]

Constructing with a high tolerance for moisture involves, in order of importance, prevention of liquid water entry into the envelope, airtight construction, and appropriate placement of vapour retarders. It also includes providing the possibility for the envelope to dry out in case of accidental wetting and avoiding thermal bridges through the thermal insulation. [50]

A consensus on moisture performance criteria and appropriate assumptions for indoor moisture and temperature conditions is needed to provide a consistent basis for moisture analysis of the exterior envelope and recommendations of moisture control strategies. Recommendations for “desirable” or “optimum” indoor humidity are not useful in regard to envelope performance or indoor air quality, because both depend on microclimatic conditions that are a function of the thermal integrity, air leakage characteristics, moisture properties of the wall, and exterior weather conditions.

Insulation is important in controlling moisture problems because it increases the temperature of the inside surfaces of walls, ceilings and floors, preventing condensation on those surfaces. In cases where mildew or dampness is appearing on the ceilings at its edges near the outside walls, there is a possibility that the ceiling insulation is not properly installed. Insulation must extend over the top plate of the wall and be fitted tightly to the top plate. Cold air can blow under insulation and chill the ceiling where vapor will subsequently condense. Similarly, wall insulation can settle, allowing cold spots to occur at the top of walls. In both cases, insulation must be repositioned or fitted in.

In the average home, moisture condensation appears first on the glass in windows and doors, because these are usually the coolest surfaces in the house. This condensation can be reduced or eliminated by installing storm window units. The air space separating the storm unit from the regular window becomes an insulator. This space allows the temperature of the storm window unit to approach the temperature of the cold outside air, while the temperature within the house or at least stay above a temperature that will cause condensation to take place on the inner unit. [49]

Many materials used as interior coverings for exposed walls, such as plastic dry wall, wood paneling and plywood, permit water vapor to slowly pass through them. When the relative humidity within the house at the surface of an unprotected wall is greater than that within the wall, water vapor will migrate through the plaster or other finish into the stud space, where it will condense if it comes into contact with surfaces colder than its dew point temperature. Vapor barriers are used to resist this movement of water vapor or moisture in various areas of the house. [49]

All construction materials have some resistance to moisture flow, but only those materials highly resistant to vapor flow should be used as vapor barriers. The permeability of the surface to such vapor movements is usually expressed in perms, which are grains of water vapor passing through a square foot of material per hour, per inch of mercury difference in vapor pressure. A material with a low perm value (1.0 or less) is a barrier, while one with a high perm value (greater than 1.0) is a breather. Membranes which best serve this purpose include polyethylene film (four to six mil.), asphalt-coated or laminated papers and kraft-backed aluminum foil. Oil base or aluminium paints and /or vinyl wallpaper are often used in existing homes which did not have vapor barriers installed during their construction. [49]

Air Tightness

It has long been recognised that the control of air flow is a crucial and intrinsic part of heat and moisture control in modern building enclosures [Wilson 1963, Garden 1965]. That this statement is true for all climates has been a more recently developed awareness [Lstiburek 1994]. A large fraction of a modern, well-insulated building's space conditioning energy load is due to uncontrolled air leakage. Wintertime condensation of water vapor in exfiltrating air (or summertime condensation of infiltrating air) within assemblies is one of the two major sources of moisture in the above-grade enclosure (driving rain being the other). Air flow through the enclosure can also carry, exhaust gases, odours, and sounds through enclosures as well as mold spores and off gassing generated within the enclosure. Uncontrolled air leakage through the enclosure is therefore often a major cause of performance (e.g. comfort, health, energy, durability, etc.) problems. [51]

Water vapour diffusion, while amenable to simple analysis, is often (but definitely not always) an insignificant source of moisture in modern building envelopes. Wintertime exfiltration condensation is, however, acknowledged as a common building performance problem in cold climates. Warm weather infiltration condensation is often a problem in warm and humid climates (e.g. the south-eastern States) and in some cases in cool climates, especially when air conditioning or cooling (e.g. arenas) is used. [51]

Therefore, there are three primary classes of reasons why the control of air flow is important to building performance:

1. Moisture control – water vapour in the air can be deposited within the envelope by condensation and cause serious health, durability, and performance problems.
2. Energy savings –air leaking out of a building must be replaced with outdoor air which requires energy to condition it. Approximately 30% to 50% of space conditioning energy consumption in many well-insulated buildings is due to air leakage through the building enclosure. Convective circulation and wind washing both reduce the effectiveness of thermal insulation and thus increase energy transfer across the envelope.
3. Comfort and health – cold drafts and the excessively dry wintertime air that results from excessive air leakage directly affect human comfort, wind-cooled portions of the interior of the enclosure promote condensation which supports biological growth which in turn affects indoor air quality, airborne sound transmission control requires good airflow control, and odours and gases from outside and adjoining buildings often annoy or cause health problems. [51]

There are other circumstances that require the control of air flow; for example, to control smoke and fire spread through air spaces and building voids and shafts, but these are situations that deal with extreme events, not typical service.

For air flow to occur, there must be both:

- a pressure difference between two points, and
- a continuous flow path or opening connecting the points.

Although the prerequisites are obvious and simple to state, in practical design applications it is not always clear what the pressure differences are or how to assess the existence and nature of flow paths. [52]

In general, the approach taken to control air flow is to attempt to seal all openings at one plane in the building enclosure. This primary plane of airtightness is called the air barrier system. The word system is used since airflow control is not provided by a material, but by an assemblage of materials which includes every joint, seam, and penetration. [52]

Wind forces act on all buildings, typically creating a positive pressure on the windward face and negative (suction) pressures on the walls. Bernoulli's equation can be used to calculate the pressure imposed on a building as function of wind speed.

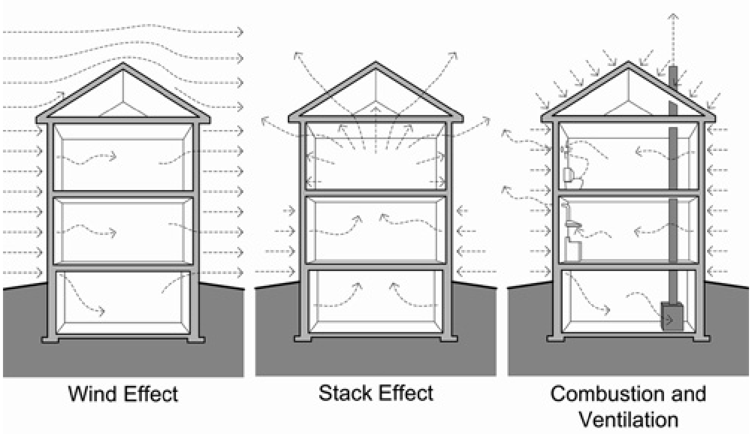


Fig. 5.68. Air Flow Inside a Residential Building

Stack effect pressures are generated by differences in air density with temperature, i.e. hot air rises and cold air sinks. The air within a building during the wintertime acts like a bubble of hot air in a sea of cold air. In the summertime the situation is reversed, although air temperature differences are usually less. [51]

Fans and blowers cause the movement of air within buildings and through enclosures. By doing so, they can generate large pressures. If more air is exhausted from a building than is supplied, a net negative pressure is generated and vice versa.

If air is forced through the ducts that leave the building enclosure or pass outside the primary air barrier system (e.g., the very bad practise of placing ductwork in vented attics or crawlspaces) any leaks in the ductwork (and all ducts have some leakage, most ductwork is very leaky) will result in a net exhaust of air, and hence a net negative inward pressures on the building enclosure. The reverse can happen if leaky ducts outside the air barrier are under a net suction pressure.

Bathroom exhaust fans, clothes dryers, built-in vacuum cleaners, dust collection systems, and range hoods all exhaust air from a building. This creates a negative pressure inside the building. If the enclosure is airtight or the exhaust flow rate high, large negative pressures can be generated. These negative pressures have the potential to cause several problems:

- by driving inward air leakage through the enclosure, outdoor air may transport moisture into the enclosure during hot humid outdoor weather conditions
- the negative pressures can cause backdrafting of combustion appliances.
- the efficiency of most air handling devices will decrease with increasing back pressures. [52]

In design, one should aim for almost no mechanically-induced air pressure across the enclosure. This is achieved by balancing systems so that the same amount of air is supplied as is exhausted. In some case pressurization can be used to control airflow direction — buildings that are depressurised in winter will not have air leakage condensation problems, buildings that are pressurized may have winter condensation problems (if the enclosure leaks) but will exclude pollution from, for example, a parking garage. [51]

Controlling the flow of air across the enclosure, e.g., from the interior to the exterior or vice versa, is the most important aspect of air flow control. While no building is perfect, the goal of a design should be near zero flow.

The primary plane of air flow control in a wall is generally called the air barrier. Because such a plane is in practise comprised of elements and joints, the term air barrier system (ABS) is preferred. In framed, low-rise residential buildings, the primary air barrier system is often comprised of an inner layer of drywall (sealed around the perimeter and at all penetrations) or sealed polyethylene. However, outer layers of sheathing, (such as gypsum, waferboard, fiberboard, EXPS) and housewrap or building paper provide additional resistance to out-of-plane air flow through the enclosure assembly. In many modern building assemblies, exterior sheathing is designed and detailed to be part of an outboard air barrier system. Note that the plane of airtightness labelled by the designer (and all building sections should indicate what is intended to be the air barrier) or builder as the air barrier system may not in fact act as the ABS. [51]

Typically, several different materials, joints and assemblies are combined to provide an uninterrupted plane of primary airflow control. Regardless of how air control is achieved, the following five requirements must be met by the air barrier system (ABS):

1. **Continuity.** This is the most important and most difficult requirement. Enclosures are 3-D systems! ABS continuity must be ensured through doors, windows, penetrations, around corners, at floor lines, soffits, etc.
2. **Strength.** If the ABS is, as designed, much less air permeable than the remainder of the enclosure assembly, then it must also be designed to transfer the full design wind load (e.g., the 1-in-30 year gust) to the structural system. Fastenings can often be critical, especially for flexible non-adhered membrane systems.
3. **Durability.** The ABS must continue to perform for its service life. Therefore, the ease of repair and replacement, the imposed stresses and material resistance to movement, fatigue, temperature, etc. are all considerations.
4. **Stiffness.** The stiffness of the ABS (including fastening methods) must reduce or eliminate deflections to control air movement into the enclosure by pumping. The ABS must also be stiff enough that deformations do not change the air permeance (e.g., by stretching holes around fasteners) and/or distribute loads through unintentional load paths.
5. **Impermeability**. Naturally, the ABS must be impermeable to air. Typical recommended air permeability values are less than about 1.3 x 10-6 $m^3/m^2/Pa$. However air barrier materials are commonly defined as materials which pass less than Q< 0.02 lps/m^2 @75 Pa. Although this is an easy property to measure it is not as important as might be thought. In practise, the ability to achieve other requirements (especially continuity) are more important to performance, and the air "permeance" of joints, cracks, and penetrations outweighs the air permeance of the solid materials that make up most of the area of the ABS. Hence, a component should have an air leakage rate of less than Q< 0.2 lps/m^2 @75 Pa, and the whole building system should leak less than Q< 2.0 lps/m^2 @75 Pa. [51]

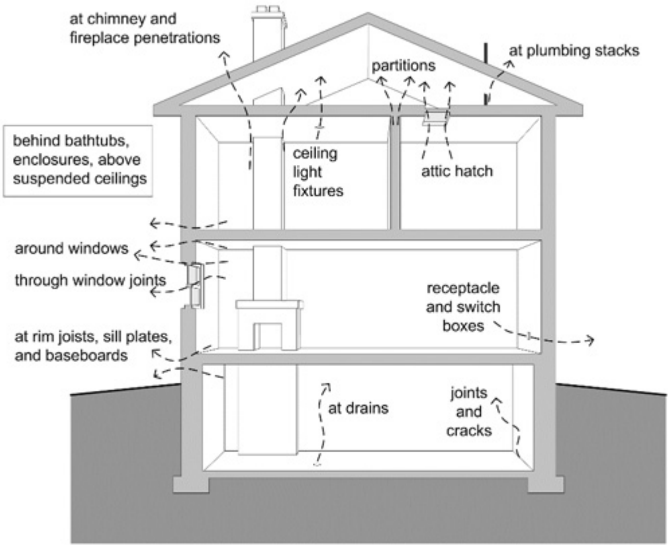


Fig. 5.69. Typical air leakage paths.

As noted earlier, the secondary planes of air flow resistance fulfill several functions, either on their own or in conjunction with the other planes of air flow resistance. These secondary barriers not only add marginally to the overall airflow resistance of the assembly, they provide a level of redundancy if the primary air barrier is designed, built, or performs imperfectly. If the secondary barrier is of sufficient air tightness it may provide a great improvement to overall airtightness so long as compartmentalisation is provided. For example, research has shown that housewraps, sometimes called air infiltration retarders, can significantly reduce airflow through an imperfect primary air barrier even if they are not designed or built as an ABS. The satisfactory performance of many older wall systems can often be explained by the unintentional, and often synergistic, contribution to airtightness that layers such as building paper, board and panel sheathing, brickwork, etc. [51]

Air flow control is important for several reasons: to control moisture damage, reduce energy losses, and to ensure occupant comfort and health. Airflow across the building enclosure is driven by wind pressures, stack effect, and mechanical air handling equipment like fans and furnaces. A continuous, strong, stiff, durable and air impermeable air barrier system is required between the exterior and conditions space to control airflow driven by these forces. [51]

Air barrier systems should be clearly shown and labelled on all drawings, with continuity demonstrated at all penetrations, transitions, and intersections. In addition, enclosure assemblies and buildings should be vertically and horizontally compartmentalized, may require secondary planes of airtightness (such as those provided by housewraps and sealed rigid sheathing) and may need appropriately air impermeable insulations or insulated sheathing. [51]

It must be noted that increased airtightness must be matched by an appropriate ventilation system to dilute pollutants, provide fresh air, and control cold weather humidity levels. Good airflow control through and within the building enclosure will bring many benefits: reduce moisture damage, energy savings, and increased health and comfort. However, while airflow usually causes wetting in enclosures, it also can be a powerful drying mechanism. Therefore, enclosures with increased air flow control demand greater attention to other sources of drying (diffusion is the only practical mechanism available) and the reduction or elimination of other sources of wetting (built-in, rain and diffusion). [51]

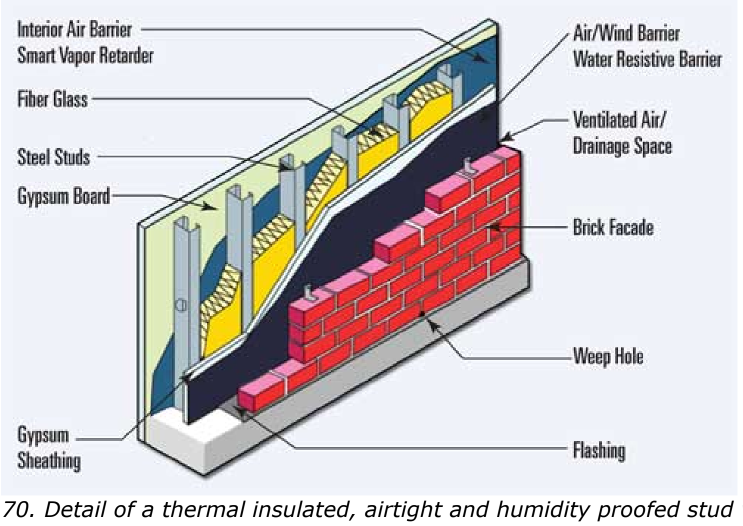


Fig. 5.70. Detail of a thermal insulated, airtight and humidity proofed stud wall

BUPT

Indoor Environmental Quality

In agreement with the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) Standard 55-66 (1966), thermal comfort for a person is here defined as 'that condition of mind which expresses satisfaction with the thermal environment'. Normally this means that the person does not know whether he would prefer a warmer or a cooler environment. Furthermore, it is a requirement that the heat loss from the person is not too asymmetrical. [53]

Thermal comfort is affected by heat conduction, convection, radiation, and evaporative heat loss. Thermal comfort is maintained when the heat generated by human metabolism is allowed to dissipate, thus maintaining thermal equilibrium with the surroundings. Any heat gain or loss beyond this generates a sensation of discomfort. It has been long recognized that the sensation of feeling hot or cold is not just dependent on air temperature alone.

Factors determining thermal comfort include:

- Personal factors (health, psychology, sociology & situational factors)
  Insulative clothing
  Activity levels
- General Factors
  Air temperature
  Mean radiant temperature
  Relative humidity (see also perspiration)
  Drifts and ramps in operative temperature
- Localized factors
  Air movement/velocity (see wind chill factor)
  Radiant asymmetry
  Floor surface temperatures (see under floor heating)
  Air temperature stratification

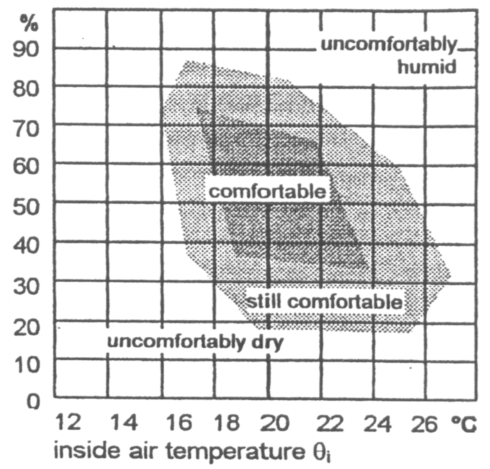
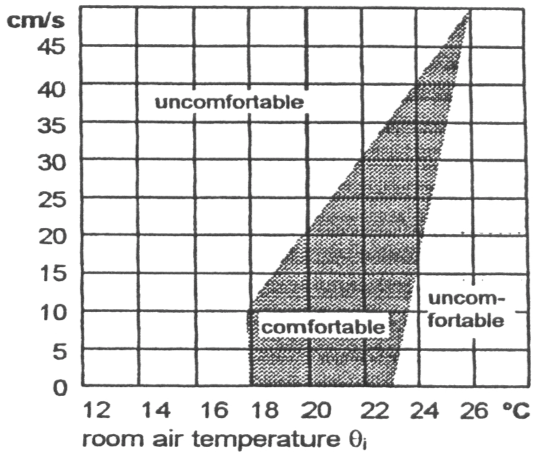


Fig. 5.71. Thermal comfort depending on temp. and relative humidity



Thermal comfort depending on temp. and air flow

People are not alike, thermally or otherwise. If a group of people is exposed to the same room climate it will therefore normally not be possible, due to biological variance, to satisfy everyone at the same time. One must then aim at creating optimal thermal comfort for the group, i.e., a condition in which the highest possible percentage of the group are thermally comfortable. Conditions are expressed in controllable factors, namely the following four main physical parameters which constitute the thermal environment:

1. air temperature
2. mean radiant temperature
3. relative air velocity
4. vapour pressure in ambient air.
5. activity level (internal heat production in the body)
6. thermal resistance of clothing. [53]

Natural light is an important component of the internal environment and modern design has evolved to exploit the architectural and environmental qualities of glass. A method based on the ASHRAE two-node comfort model has been developed for predicting the effect of windows on thermal comfort. The method embodies separate analyses for long-wave (thermal infrared) radiation, induced drafts, and solar load effects. Of these three impacts, modelling results demonstrate that long-wave exchange between the body and the window is the most significant except for the case where the body is in direct sun, in which case the impact solar load can be more significant. For most residential-size windows, draft effects exist but are typically small. [54]

Generally, windows are not the primary element affecting the comfort of a building's occupants. However when a window is very hot or cold, the occupant is very close to the window, or other factors result in thermal conditions near the edge of the comfort zone, windows can become quite influential. [54]

Furthermore it is believed that current methods may under-predict discomfort caused by windows. In *winter*, radiant heat loss toward a cold window surface, drafts induced by cold air drainage off the window surface, and temperature asymmetry between the room and the window can make an occupant feel uncomfortable, particularly if he or she is sedentary. In *summer*, solar gains from direct transmission and by re-radiated heat from absorbed energy may subject occupants in the perimeter zone to radiant temperatures above 60°C, which may make perimeter zones uncomfortable. [54]

The thermal transmittance of glass can be reduced in several ways including the use of low-e coatings or inert gases such as argon or krypton within the glazing cavity. Such enhancements make it possible to reduce mid-pane U-values to 0.85 W/m^2K for triple-glazed units. [54]

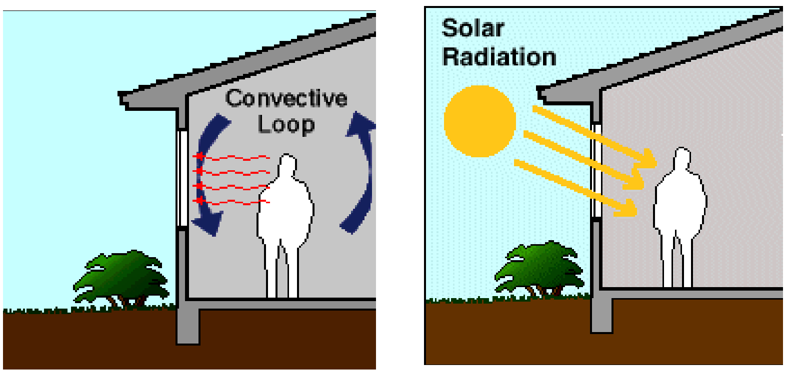


Fig. 5.72. Convective, long-wave radiative and short-wave solar effects on thermal comfort.

The performance of the glass is, however, only part of the problem and the frame and associated edge condition is usually the weak point for thermal transmittance, particularly for curtain wall. Clients and project teams must be careful not to confuse mid-pane U values with the overall U-value for a facade, which will always be significantly lower. [54]

Insulation within the frame sections, thermal breaks and so on mitigate the problem, but there is no escaping the fact that the introduction of more framing members, around opening lights or solid insulated panels for example, has a detrimental impact on the overall thermal performance of the walling system.

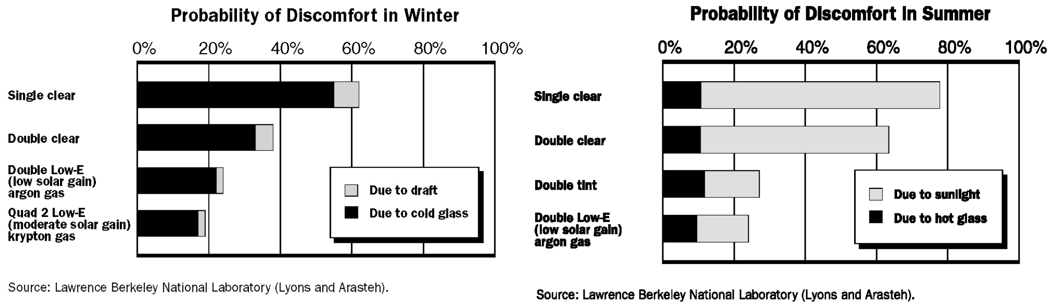


Fig. 5.73. The effect of the windows on thermal comfort

The contribution by glazing systems to other aspects of thermal performance are as follows:

- Air infiltration rates as low as $3m^3/m^2/hr$ @ 50Pa can be achieved using unitised curtain wall. With windows, sealing within the units is typically very good, but overall airtightness is reliant on on-site installation and supervision. Improvements in the airtightness of window units have necessitated the development of more sophisticated trickle ventilation systems, often at a premium cost.
- Glazing systems can be used to mitigate solar gain through either the incorporation of solar shading or the specification of solar-control coatings, which are applied to the inner face of the outer pane of double-glazed units. Low-tint, solar-control coatings known as “super neutrals” cut out up to 63% of solar gain, but cannot be bent or curved due to the soft coating used. Where bent or curved panels are required, hard coatings with a deeper tint need to be specified. [54]

New high-performance windows alleviate thermal discomfort by reducing heat loss and/or heat gain and can lower heating, cooling, and electric lighting costs. They also exhibit inside surface temperatures that are closer to room air temperature, resulting in less thermal discomfort for the occupants. Glass and frame temperatures are readily calculated for specific environmental conditions using established computer design tools. However, human thermal sensations and comfort criteria are not as easily quantified. Numerous studies address thermal comfort in general but do not focus specifically on quantifying the impact of windows. [54]

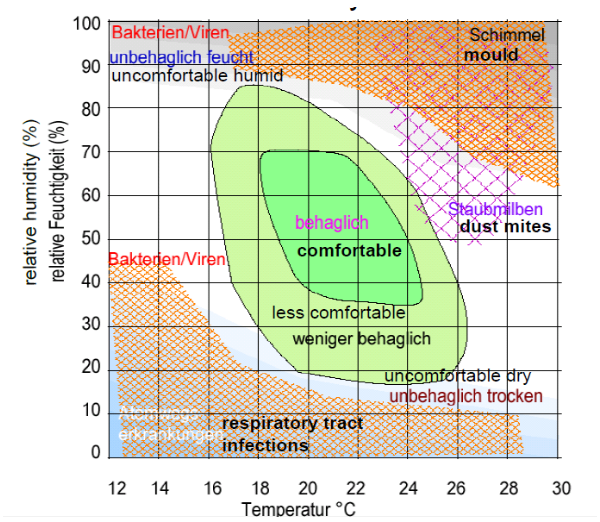


Fig. 5.74. Occupants of households are usually comfortable when the temperature and relative humidity are maintained within the ranges of 20 to 22 degrees and 40 to 60 percent.

One of the fastest growing sources of new energy demand is space cooling.Despite the available knowledge and technologies of low energy and passive cooling, cooling energy consumption is dramatically increasing in Europe. The studies EECCAC and EERAC predict a four-fold growth in air-conditioned space between 1990 and 2020 (Adnot et al, 1999; 2003). [55]

Passive cooling techniques are already available and cost effective (such as use of well designed sun shades, efficient lighting and office equipment, passive cooling via thermal exchange with the ground, night ventilation etc.). However, they are not widely used on the market today: the most common choice for a building owner when addressing summer comfort issues is still mechanical cooling, often without investigating other available measures. [55]

The IEA Future Building Forum named cooling as one of the fastest growing sources of new energy demand (International Energy Agency, 2004). The preamble of the European Energy Performance of Buildings Directive (EPBD) states: "Recent years have seen a rise in the number of air-conditioning systems in southern European countries. This creates considerable problems at peak load times, increasing the cost of electricity and disrupting the energy balance in those countries. Priority should be given to strategies which enhance the thermal performance of buildings during the summer period. To this end there should be further development of passive cooling techniques, primarily those that improve indoor climatic conditions and the microclimate around buildings" (European Communities, 2003). [55]

5.6. Electrical and HVAC Design

The design of electrical systems in residential settings is an important topic in construction. Lighting schemes and products are so vast that there are endless options for a homeowner, so it is up to the electrical contractor and electrical engineer to take what the homeowner wants and apply the correct electrical design to the house. It is also important from an efficiency point of view to use products that save electricity.

The design of lighting system requires the following:

- Lighting load estimations and determining numbers of feeder for lighting panel
- Light fixture layout designing involving normal, emergency, critical and life safety
- Light fixtures identification as per your standards and occupancy sensors, dimmers etc., their selection, and placement at appropriate location
- Calculating the lux levels for each classified areas together with lighting controls requirements for power savings
- Worst-case egress lighting estimation
- Lighting distribution panel design and designing emergency panel
- Determining the lighting panel location based on provided inputs
- Switchgear sizing
- Determining transformer size for lighting distribution system

The Design of Power System

- Calculating the loads for electrical and electronics equipments
- Calculating the connected load on each circuits
- Determining the receptacle, electrical and electronics equipments for all areas
- Lighting distribution panel design and designing emergency panel
- Designing the life safety and determining earth protection requirements
- Switchgear sizing
- Determining transformer size for power distribution

Design of Power Distribution System

- Calculating the total power requirements
- Determining power factor correction requirements
- Calculating power and lighting load determination on the basis of actual connected equipment with appropriate demand/diversity factors, as per your standards
- Determining the main transformer requirements
- Determining the size of generator
- Determining the HV equipments, metering and protective switchgear requirements
- Determining cable trays, trenches their optimum path
- Switchgear sizing
- Determining the cable and wire sizing
- Determining the one line diagram for distribution system

Design of Fire Protection System

- Determining the numbers of circuits and device types according to defined areas
- Control circuits for integration with building management systems
- Determining the integration requirements with respect to annunciation, automatic dialing and building management systems
- Fire detector, enunciator, manual points and panel layout
- Control diagram for remote panels and main panels
- Riser diagram, device and panel schedule

Drafting of lighting, power and power distribution system

- Layouts of lighting depicting different lighting fixture, egress and emergency lighting, occupancy sensors etc.
- Power layout plan showing receptacles, refrigerator, microwave, freezer, ice machine, cabinet heater, coffee machine etc.
- Drafting of luminaries, power equipments, devices counts, terminations diagrams, control circuits, LV/HV electrical devices, panel schedule, material list

A green strategy for designing a residential electrical system can be summed up in three words: Use less power. As our supply of fossil fuels decrease and the price increases people are much more concerned about how green energy in their homes can save resources and money. Heating, cooling and lighting consume 67% of all the electricity that's generated.

Here are some measures that can be taken in order to reduce energy consumption:

- Providing power strips that can be switched off. Phantom loads can have a surprising electric draw. TV's and other appliances should be unplugged when not in use.
- Replacing all incandescent bulbs with compact fluorescent/LEDs - 90% of the energy that goes into an incandescent bulb is given off as heat, not light. LED's and fluorescent are much more efficient and save the homeowner money on their energy bills. These lights cost more initially, but save money in the long run. These lights are readily available at most home stores

- Installing dimmer switches to help save energy. The full power of a light is not always needed. Dimmers save energy and provide ambiance.
- Replacing toggle switches with dimmer switches
- Placing a foam gasket around outlets and switches - air infiltration is a huge problem and the source of much energy waste. It is important to seal even the small air gaps around an electrical outlet as they have a big impact over the life of the building.
- Replacing home appliances with energy efficient models. These appliances are installed in the same way as older models and require no addition work.
- Installing adequate lighting fixtures. Many homes have more light fixtures than are needed. Install fixtures to light a specific task area. Lights should be controlled by several switches so that only the lights that are needed are switched on.
- Consulting with a lighting designer and the homeowner, in order to outline the specific lighting needs. Install fixtures that will maximize light output.
- Minimizing recessed cans or eliminate them entirely
- Installing of programmable thermostats. Programmable thermostats save energy by allowing homeowners to set the house to a lower temperature when they are not home
- Designing conduit for future solar panels. Conduit is much easier to install while a home is being built or remodeled rather than trying to fit it in after the fact. This process is cheap and easy. Clients will reap the benefits if they later choose to install panels.

HVAC (pronounced as four separate letters) is an acronym that stands for "heating, ventilating and air-conditioning" and generally includes a variety of active mechanical/electrical systems employed to provide thermal control in buildings. Control of the thermal environment is a key objective for virtually all occupied buildings. For thousands of years such control may have simply been an attempt to ensure survival during cold winters. In the modern architectural context, thermal control expectations go far beyond survival and involve fairly complex thermal comfort and air quality concerns that will influence occupant health, satisfaction and productivity. [56]

A heating system ("H" in HVAC) is designed to add thermal energy to a space or building in order to maintain some selected air temperature that would otherwise not be achieved due to heat flows (heat loss) to the exterior environment. A ventilating system ("V") is intended to introduce air to or remove air from a space - to move air without changing its temperature. Ventilating systems may be used to improve indoor air quality or to improve thermal comfort. A cooling system ("C" is not explicitly included in the HVAC acronym) is designed to remove thermal energy from a space or building to maintain some selected air temperature that would otherwise not be achieved due to heat flows (heat gain) from interior heat sources and the exterior environment. Cooling systems are normally considered as part of the "AC" in HVAC; AC stands for air-conditioning. [56]

An air-conditioning system, by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) definition, is a system that must accomplish four objectives simultaneously. These objectives are to: control air temperature; control air humidity; control air circulation; and control air quality. Although the word "control" is often loosely construed, encompassing anything from pin-point control for central computer facilities to ballpark control for residences, the requirement that an air-conditioning system simultaneously modify four properties of air demands reasonably sophisticated systems. Heating systems (such as portable electric heaters or fireplaces), ventilating systems (such as whole-house fans or make-up air units), and sensible-cooling-only systems are also used in buildings. [56]

The basic purpose of an HVAC system is to provide interior thermal conditions that a majority of occupants will find acceptable. Occasionally this may simply require that air be moved at an adequate velocity to enhance convective cooling and evaporation from the skin. Much more commonly, however, providing for occupant comfort will require that an HVAC system add or remove heat to or from building spaces. In addition, it is normally necessary for moisture to be removed from spaces during the summer; sometimes moisture will need to be added during the winter. The heat and moisture control functions of HVAC systems provide the foundation for key system components. The additional functions of air circulation and air quality control establish further component requirements. In specific building situations, supplemental functions, such as controlling smoke from fires or providing background noise for acoustic privacy, may be imposed on an HVAC system - along with a potential need for additional components. [56]

Each building has a characteristic exterior air temperature, known as the balance point temperature, at which the building in use would be able to support thermal comfort without the need for a heating or cooling system. At the balance point temperature, which is strongly influenced by internal loads and envelope design, building heat gains and losses are in equilibrium so that an appropriate interior temperature will be maintained naturally and without further intervention. When the outside air temperature falls below the balance point temperature, heat losses through the building envelope will increase - and interior air temperature will drop unless heat is added to the building to compensate. A system that provides such additional heat is called a space (or building) heating system. When the outside air temperature exceeds the balance point temperature, heat gain through the building envelope will upset thermal equilibrium and cause the interior air temperature to rise. A system that removes such excess heat is called a cooling system. [56]

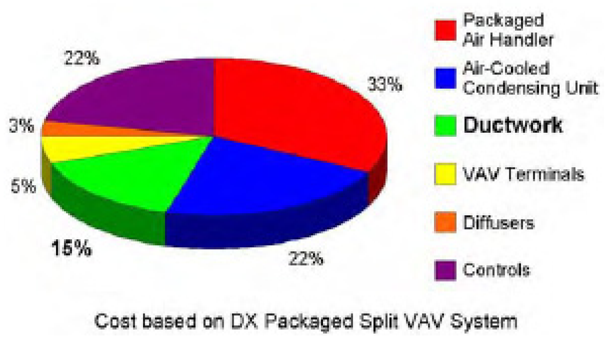


Fig. 5.75. Example of HVAC Cost Breakdown

Space heat may be added or removed by an electro-mechanical system, which is termed an active systems approach. An active system has the following general characteristics: it normally utilizes purchased energy for its operation, it requires special-purpose components that serve no other major building function, and it is generally relatively independent of the underlying architectural elements of the building. Alternatively, space heat may be added or removed by a system designed to make use of naturally occurring environmental forces. Such a system is termed a passive system. A passive system has the following general characteristics: it utilizes renewable site resources for energy inputs, it usually involves components that are integral parts of other building systems, and it is usually so tightly interwoven with the basic architectural fabric of a building that removal would be difficult. [56]

Control of an HVAC system is critical to its successful operation. The issue of system control leads to the concept of HVAC zoning. During the design process, a zone is defined as a region of a building that requires separate control if comfort is to be provided for occupants. In an existing building, a zone is easily identified as an area operated from a single control point (typically a thermostat in an active system). Zoning is very much an architectural responsibility as it requires an understanding of building function and schedules. Typically the two key elements to consider when establishing thermal zones are differential solar radiation exposures (a north facade versus an east facade) and differential operating schedules and loading requirements (an occasionally used assembly hall versus a normally occupied office suite). Thermal zones must be established very early in the HVAC system design process. [56]

Active HVAC systems may be designed to condition a single space (or portion of a space) from a location within or directly adjacent to the space. Such a system is known as a local system. Other HVAC systems are designed to condition several spaces from one base location. Such a system, easily identified by components that distribute conditioning energy across space boundaries, is known as a central system. [56]

HVAC system components may be grouped into three functional categories: source components, distribution components, and delivery components. Source components provide or remove heat or moisture. Distribution components convey a heating or cooling medium from a source location to portions of a building that require conditioning. Delivery components serve as an interface between the distribution system and occupied spaces. Compact systems that serve only one space or zone of a building (local systems) often incorporate all three functions in a single piece of equipment. Systems that are intended to condition multiple spaces in a building (central systems) usually have distinctly different equipment elements for each function. [56]

Four distinctly different types of heat sources are employed in buildings. Heat may be generated by the combustion of some flammable material (a fuel) such as coal or natural gas. Electricity may be converted to heat through the process of electric resistance. Solar radiation or other renewable energy resources may be collected on site and converted to heat. Heat may be removed from some material on site and transferred into a building. All four of these fundamental heat sources find common use in all scales of buildings. The choice of a heat source for a given building situation is usually based upon source availability, required system capacity and equipment, and fuel costs. [56]

Although cooling is technically just a reverse heat flow -- the flow of heat into a sink, rather than from a source - sources of cooling (heat sinks) are not always readily available. The term "coolth" is sometimes used to identify the product of heat flowing to a sink. Identification of coolth sources is actually the identification of available heat sinks. Heat sinks of interest to building design are either naturally occurring environmental phenomena or artificially induced phenomena. Naturally occurring heat sinks include outside air - its sensible (temperature) and latent (humidity) conditions, on-site water bodies, and on-site soil. Use of such natural sinks is the basis for passive cooling systems. Unfortunately, the availability and/or capacity of natural heat sinks is often exceptionally limited during overheated periods of the year, making passive cooling most difficult when most needed. Active system heat sinks are artificially established through the operation of some type of refrigeration device. There are three main refrigeration approaches employed in buildings: vapor compression (mechanical) refrigeration, absorption (chemical) refrigeration, and evaporative cooling. The choice of a coolth source is usually based upon resource availability, energy and equipment costs, and appropriateness to the building context. [56]

HEAT SOURCE	PASSIVE		ACTIVE			
	LOCAL	CENTRAL	LOCAL	CENTRAL	Distribution	Delivery
On-Site Combustion	Fireplace, Stove	Convective Furnace	Unit Heater	Furnace Boiler Boiler	Ducts (air) Pipes (water) Pipes (steam)	Diffusers or registers Baseboard radiators AHU heating coils
Electrical Resistance	N/A	N/A	Unit Heater, Portable Heater, Electric Baseboard	Furnace or AHU Boiler	Ducts (air) Ducts (air) Pipes (water)	Diffusers or registers Diffusers or registers Radiant panels
Heat Transfer	N/A	N/A	Heat Pump— Window or Split	Central Heat Pump	Ducts(air) Pipes (water)	Diffusers or registers Coils or other devices
Heat Collection	Direct gain Indirect gain	Isolated gain	N/C	Air Heating, Water Heating	Ducts (air) Pipes (water)	Diffusers or registers Radiators or coils

Notes: this table should in NO way be considered a comprehensive listing of all possible building heating options — it simply provides an overview of typical systems and common applications; N/A = not applicable; N/C = not common; AHU = air handling unit.

Tab. 5.8 – Building Heating Sources Matrix

HEAT SINK	PASSIVE		ACTIVE			
	LOCAL	CENTRAL	LOCAL	CENTRAL	Distribution	Delivery
Ambient Outside Air (Sensible)	Local Ventilation [window]	Central Ventilation [stack]	Local Ventilation [window fan]	Central Ventilation [fan]	Ducts or building spaces	Diffusers/registers; Openings/spaces
Ambient Outside Air (Latent)	Evaporative Cooling	N/C	Evaporative Cooler	Evaporative Cooler	Ducts or building spaces	Diffusers/registers; Openings/spaces
Water from Site	N/A	N/A	N/C	AHU with water coil	Ducts	Diffusers/registers
Soil (Earth)	Indirect Contact	N/A	N/C	Ground source heat pump	Ducts	Diffusers/registers
Night Sky (Radiation)	Direct or Indirect	N/A	N/A	Ice-making system	Ducts (with AHU)	Diffusers/registers; Fan coils
Active Heat Transfer	N/A	N/A	Refrigeration [vapcom]	Refrigeration [vapcom, abs]	Ducts (with AHU) [central A/C]	Diffusers/registers; Fan coils

Notes: this table should in NO way be considered a comprehensive listing of all possible building cooling options — it simply provides an overview of typical systems and common applications; N/A = not applicable; N/C = not common; AHU = air handling unit; vapcom = vapor compression; abs = absorption.

Tab. 5.9 – Building Cooling Sources Matrix

Although often driven by availability or consumer economics, the choice of a heat source and/or source of cooling will have architectural ramifications that must be considered during design.

HEAT SOURCE	TYPE	EXTERIOR ISSUES	INTERIOR ISSUES	OTHER ISSUES
On-Site Combustion	Wood	Wood storage, flue, combustion air	Dry storage, flue, equipment	Ash removal
	Gas	Meter, flue, combustion air	Flue, equipment	
	Oil	Fuel inlet, flue, combustion air	Storage tank, flue, equipment	
	Coal	Fuel inlet, flue, combustion air	Storage bin, flue, equipment	Ash removal
Electrical Resistance	Various	Normal service entrance	Equipment, circuitry	
Heat Transfer	Air source	Condenser unit	Equipment	
	Water source	Cooling tower, well	Equipment, (integration)	
	Ground source	Heat "field"	Equipment	
Heat Collection	Active	Collectors (area, tilt, orientation)	Equipment (additional)	Back-up system
	Passive	Aperture (area, orientation)	Storage, controls, distribution	User intervention
District Heating	Water	Connection to off-site source	Pumps, equipment (less source)	
	Steam	Connection to off-site source	Heat exchanger, equipment (" ")	

Note: this table should in NO way be considered a comprehensive listing of all possible building heating concerns - it simply provides an overview of typical systems and common architectural integration issues.

Tab. 5.10 – Building Heating Systems – Architectural Implications Matrix

Building Cooling Systems - Architectural Implications Matrix

HEAT SINK	TYPE	EXTERIOR ISSUES	INTERIOR ISSUES	OTHER ISSUES
Ambient Outside Air (Sensible)	Local vent (P)	Inlet/outlet openings, orientation	Spatial layout w/r/t air flow	Comfort ventilation
	Central vent (P)	Inlet/outlet openings, orientation	Air circulation paths, layout	Structural ventilation
	Local vent (A)	Inlet opening, outlet, possibly fan	Spatial layout w/r/t air flow	Security, privacy, dust
	Central vent (A)	Inlet opening, outlet	Equipment space, layout/ducts	
Ambient Outside Air (Latent)	Evap. cooling (P)	Inlet-water source arrangement	Spatial layout w/r/t air flow	Materials selections
	Evap. cooler (A)	Equipment location/inlet	Spatial layout or ductwork	Maintenance
Water from Site	AHU/water coil	Water source	Equipment space, distribution potential	Latent cooling
Soil (earth)	Earth contact (P)	Soil depth, type, vegetation	Spatial layout	Regional issues
	Ground source (A)	Soil type, vegetation	Equipment space, distribution	
Night Sky Radiation	Building parts (P)	View of sky, surface area	Spatial layout	Seasonal issues
	Equipment (A)	Location, area	Equipment space	Experimental
Heat Transfer	Refrigeration	Condenser location	Evaporator location, equipment	Local/central

Note: this table should in NO way be considered a comprehensive listing of all possible building cooling concerns — it simply provides an overview of typical systems and common architectural integration issues; (P) indicates passive; (A) indicates active; w/r/t means with respect to; AHU = air handling unit; Evap. = evaporative.

Tab. 5.11 – Building Cooling Systems – Architectural Implications Matrix

HVAC systems are of great importance to architectural design efforts for four main reasons. First, these systems often require substantial floor space and/or building volume for equipment and distribution elements that must be accommodated during the design process. Second, HVAC systems constitute a major budget item for numerous common building types. Third, the success or failure of thermal comfort efforts is usually directly related to the success or failure of a building's HVAC systems (when passive systems are not used) - even though the HVAC systems should be viewed as part of the larger architectural system. Last, but not least, maintaining appropriate thermal conditions through HVAC system operation is a major driver of building energy consumption. This is why the following guidelines should be noted for energy efficiency:

1) Shape: The shape of the building has influence on the cooling and heating load. Ideally the building has to have the least aspect ratio (length/width ratio). The lower aspect ratio means the building has the least surface area of the building envelope (least wall area, glazing area and the roof area).

2) Latitude: In the lower latitudes there is total overheating, whereas in the higher latitudes overheating only occurs during the summer months.

Any breeze in the lower latitude (tropical and arid climates) is beneficial for most of the year whereas in higher latitudes most wind is detrimental and should be screened.

3) Orientation: As a general guide, long, narrow buildings facing south with their long axis running east/west will have lower peak cooling loads and may be able to utilize smaller cooling equipment.

Buildings facing east or west with their long axis running north/south will have higher peak cooling loads and electricity demand costs, and may require larger cooling equipment.

4) Landscaping: Trees planted on the east, west and south sides of a one-or two-story building can effectively reduce summer solar heat gains through windows, which is one of the major contributors to the cooling load on an air conditioning system. External shading with vegetation with natural deciduous trees is very effective at providing shade and cooling by evaporating water through their leaves: during winter they are bare, allowing sunlight to pass through, but during summer they shade the building.

5) Day lighting: Day lighting with skylights and other types of architectural glazing features can provide natural lighting creating a pleasant working atmosphere.

6) Shading: Shading devices are designed from knowledge of the suns azimuth and altitude along with the wall-solar azimuth. In the temperate zone, cross ventilation and shielding are both necessary (for summer and winter, respectively).

7) Zoning for transitional spaces: Transitional areas are one that does not require total climate control and natural ventilation may be sufficient. These include lobbies, stairs, utility spaces, circulation, balconies and any other areas where movement take place. In temperate and cool zones the transitional spaces should be located on the south side of the building to maximize solar gain.

8) Use of atrium: For the cool and temperate zones the atrium should be at the centre of the building for heat and light.

9) Potential of roof/ground floor as useable exterior space: In tropical and arid climates there is a high potential to make use of all external spaces, whereas moving towards the northern latitudes the external spaces have to be covered.

10) Vertical cores and structure: The arrangement of primary mass can be used as a factor in climatic design as its position can help to shade or retain heat within the building form. The arrangement of the primary mass in the temperate zone is on the north face, so as to leave the south face available for solar heat gain

during the winter. The cool zone requires the maximum perimeter of the building to be open to the sun for heat penetration. Therefore the primary mass is placed in the centre of the building so as not to block out the sun's rays and to retain heat within the building. [57]

Central systems produce a heating and/or cooling effect in a single location. This effect must then be transmitted to the various spaces in a building that require conditioning. Three transmission media are commonly used in central systems: air, water, and steam. Hot air can be used as a heating medium, cold air as a cooling medium. Hot water and steam can be used as heating media, while cold water is a common cooling medium. A central system will always require distribution components to convey the heating or cooling effect from the source to the conditioned locations. [56]

The heating or cooling effect produced at a source and distributed by a central system to spaces throughout a building needs to be properly delivered to each space to promote comfort. In air-based systems, heated or cooled air could theoretically just be dumped into each space. Such an approach, however, does not provide the control over air distribution required of an air-conditioning system. In water-based systems, the heated or cooled media (water or steam) can not just be dumped into a space. Some means of transferring the conditioning effect from the media to the space is required. Devices designed to provide the interface between occupied building spaces and distribution components are collectively termed delivery devices. [56]

HVAC systems may be generally classified as heating only, ventilating only, cooling only, or air-conditioning systems. HVAC systems may also be classified as either local or central systems.

A local HVAC system serves a single thermal zone and has its major components located within the zone itself, on the boundary between the zone and the exterior environment, or directly adjacent to the zone. In general, space conditioning energy (heat or coolth) from a local system will not pass through another zone on its way to the space being conditioned. Serving only a single zone, local HVAC systems will have only one point of control - typically a thermostat for active systems. A portable electric heater being used to heat a living room represents a local space heating system - the equipment is located in the room being heated, the heater realistically serves no other building space, and the output enters the room directly without passing through other building spaces. Each local system generally does its own thing, without regard to the performance or operation of other local systems. Although a local system is truly an isolated system, it is common to view a collection of such independent elements as part of a larger full-building HVAC system. This view is not unreasonable - even though there is no formal structure connecting the separate units to forge a larger system. [56]

A central HVAC system may serve one or more thermal zones and has its major components located outside of the zone or zones being served -- usually in some convenient central location in, on, or near the building. Space conditioning (thermal) energy from a central system must pass through zone boundaries on its way to the space or spaces being conditioned. Central HVAC systems will have as many points of control (thermostats) as there are zones. The nature of the thermal energy transfer medium used by a central system provides a means of sub-classifying central HVAC systems. If conditioning is transferred only by means of heated or cooled air, the system is termed an all-air system. If conditioning is transferred only by means of hot or chilled water, the system is termed an all-water system. If conditioning is transferred by a combination of heated/cooled air and hot/chilled water, then the system is termed an air-water system. [56]

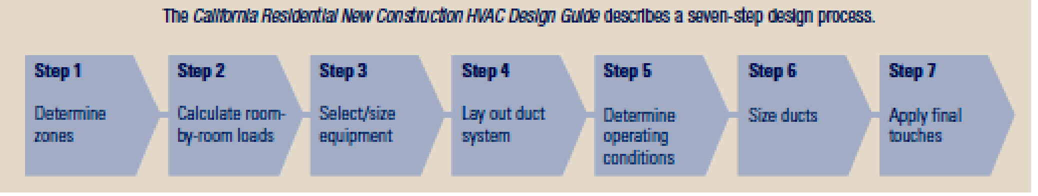


Fig. 5.76. HVAC Design Steps

The challenge to system designers and facility executives is achieving goals for improved system performance, efficiency and security without making systems unaffordable or unmanageable. Fortunately there are options that must be explored by designers pursuing high performance buildings. Here are some basic principles to consider:

1) Physically smaller HVAC equipment requires less overall space and improves core efficiencies as compared to larger HVAC equipment.

2) Moving less air results in lower fan horsepower, less sound attenuation, smaller equipment and smaller ductwork.

3) Quieter HVAC equipment requires less sound attenuation and minimizes special architectural room construction when compared to nosier HVAC equipment.

4) Moving less water will result in smaller piping systems, smaller pumps, and lower pump horsepower.

5) Smaller pump motors, smaller fan motors, and lower refrigeration horsepower require smaller electrical systems and use less energy.

6) Concentrating the major electrical loads such as large motors and refrigeration equipment near the electrical utility service entrance is usually less expensive than locating large electrical loads at a greater distance from the electrical service entrance.

7) Using fewer materials and smaller equipment minimizes environmental impact. [57]

If an architect is to maintain any semblance of control over the total building design process, he or she must understand HVAC systems. HVAC systems consume an important part of the building construction budget, account for a major portion of a typical building's annual energy consumption, often require substantial space allocations (that may drive building organization schemes in larger buildings), and contribute to interior environments that are critically evaluated by building occupants on a day-by-day basis. Successful HVAC systems are often the key to successful buildings. Although it is unlikely that an architect will fully design an HVAC system, even for residential projects, it is critical that the architect manage the system design and component selection processes to retain control of the final building product. Such management requires an understanding of system objectives, the role of key system components, the types of systems that are available, and what such systems can and can not accomplish. Overseeing HVAC system development from a broad building-wide perspective, the architect can (and usually will) leave the specifics of system design to consulting engineers. [56]

5.7. Measuring and Monitoring Building Performance

The performance of a building is estimated mainly based on its energy consumption, comparing it against some base minimum energy performance such as the ASHRA E/IESNA Standard 90.1. The larger the improvement over the base energy performance the higher the building is performing. If a new building has exceeded the estimated base performance by 42% or an existing building by 35% (LEED criteria for optimizing energy performance) they have reached the highest level of building performance. But what if an existing building has exceeded the base energy performance by 35% but is unsafe, unprofitable or isn't satisfying it occupants? Is it still a high performance building? [58]

Energy consumption and sustainability are critical in buildings, but the view that only energy defines a building's performance is myopic. Given the high energy awareness, that statement may sound like heresy. But the fact is that most buildings are too complex to be evaluated on just energy consumption. Aside from energy and sustainability we need to examine other factors of a building's performance While energy and sustainability are important unto themselves, they influence or affect some of the other building performance factors. [58]

The first factor to be taken into consideration is the financial aspect. It may seem crass to shift from saving the environment to money, but all buildings from modest houses to the tallest skyscrapers have financial aspects. Buildings are a business with whole industry sectors dealing with design, construction, management and investments in buildings. [58]

Financial concerns cut across the lifecycle of a building; the construction or acquisition cost of the building, the buildings operations costs and the asset value of the building. While there's not a standard similar to ASHRE/IESNA to benchmark minimum financial performance of a building, there is data on comparable buildings which could be used to at least judge whether the building is above or below average financial metrics of similar buildings. The examination of basic balance and income reports for a building for profit and loss, increases or decreases to income, expenses and asset valuation can be used to judge financial performance. Also, while energy and sustainability initiatives have a social and resource conservation basis, the impetus for many is financial. A large part of the motivation behind conservation, alternative energy sources, demand response and so forth is to save money. [58]

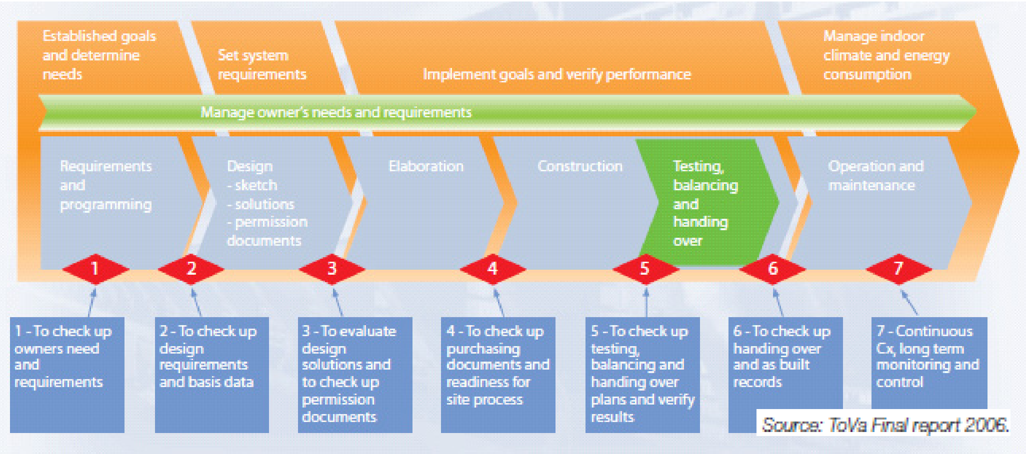


Fig. 5.77. Commissioning systems for the different phases of building life cycle.

Next, comes the satisfaction of the building occupants. One of the performance criteria of a building should be how well it enables its occupants to work, play, sleep, eat, socialize, educate, learn, and a host of other things. This involves the comfort of the occupants, both physically and psychologically. The physical part is straightforward involving thermal comfort, appropriate lighting for the occupants' activity, the occupant's control of the lighting and air distribution, the workspace layouts and the technology systems available to the occupants to make their tasks easier. These technology systems may be systems for digital signage, Wi-Fi, in-building cell phone coverage, asset location systems, audio video systems and so forth. The physiological effect may relate to the building's image, appearance and aesthetics. [58]

Building owners will need to use comparable data, interviews, observations, surveys, tests, and demographic and financial data to evaluate building performance factors. While energy performance is certainly an important aspect, the vision needs to be broader and more holistic.

5.8. Conclusions to Chapter 5

Due to the increasing complexity of buildings and building components, the plethora of building materials available, and the stringent requirements of energy codes, the integrated design approach is quickly replacing the traditional mentalities of the past. Architectural and structural conceptual designs have to happen simultaneously if possible, in fact to overlap to some extent, in order to set the path for the integrated design team.

The service life of a building is to a large extent determined during the design stage. Durable materials are required, architectural foresight, and a building that can be adapted to the future needs of the market.

The use of steel in residential construction confers a great degree of design elasticity to practically every solution. The presence of steel in the structural component itself can be of 100% or less, if combined with wood, with direct effects on construction costs. Further, steel framing can be combined much easier with various types of building envelopes, than traditional wall masonry structures.

Insulation is a key determinant of health, comfort levels and energy use in homes and hence an important aspect of overall energy sustainability.

Energy consumption during the use of a building is up to ten times greater than when it is being produced. Therefore, it is important to design and build for low energy consumption. Energy consumption during use also depends on life style. The consumption of resources during use refers primarily to the energy consumption of the building and the possibilities of replacing elements. Energy consumption in a building with a light frame is not higher than for a building with a heavy frame where heat storage can be utilized.

6. Applications and Case Studies

6.1. Introduction

Chapter 6 presents seven low rise residential examples having the design based on sustainable building construction principles and technology. All the examples have a steel structural system.

The following types of steel structures were used.

1. Lightweight stud wall
2. Hot rolled main frame with steel studs secondary structure
3. Hot rolled main frame with wood studs secondary structure

Out of the seven examples, three are case studies (in bold) and four are applications;

Single detached one story with pitched roof- 2 examples- House B and House DM

Single detached two and three story houses-3 examples-House C, House P and House B

Urban Vila/Low rise apartment building – 1 example

Housing research project- 1 example

Five of the seven examples presented are built and inhabited, one is in the final design phase and the last is a research project. All the examples are located in Romania, in medium and high risk seismic regions.

The driving design concept was to provide for flexible layouts, building upgrading, quality construction and high thermo-energetic performance, all to be achieved at a reasonable cost.

6.2. B House, Timisoara, Romania, 1999

Architectural Design

The architectural design concept is dominated by the compactness of the volume, which is in tune with the traditional rural houses in the Banat region of Romania, mainly in the areas where the Austrian colonization of 1718, is more pronounced.

This two storey house with a gross built area of 198.2 m^2, of which the ground floor represents 117.5 m^2 was intended to be the first in a series of 40 units to be built in Timisoara, Romania. This first house was supposed to be a test run meant to gauge the performances of both structural and building solutions adopted. Therefore the volume was kept as simple as possible, based on a rectangular layout. A terrace towards the garden was attached to the volume, in order to make it more lively.

The architecture is inspired by the Riehl House by Mies van der Rohe, in the sense that little detail and symmetry was used to solve a very simple volume.

Fig 6.1 - Riehl House, Postdam 1907- Mies van der Rohe

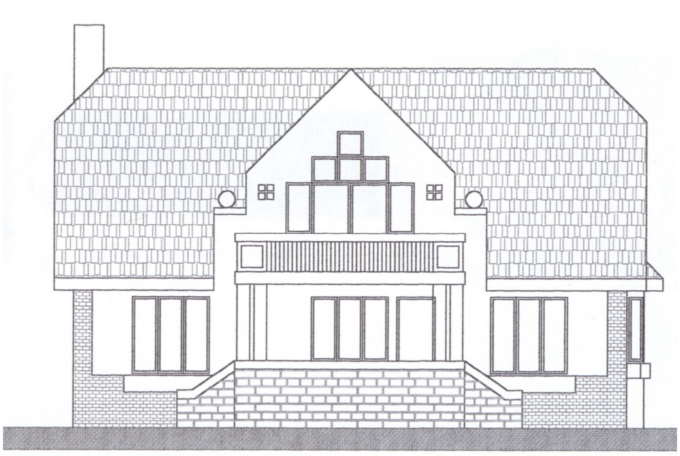


Fig. 6.2 - B. Family House, Timisoara, M. Mutiu arch. Garden Elevation

The floors layouts are rather conventional, with little room for flexibility, given the characteristics of steel stud construction, where the continuity of loadbearing walls has to be ensured. The stair is located in a double height space which accentuates the entry.

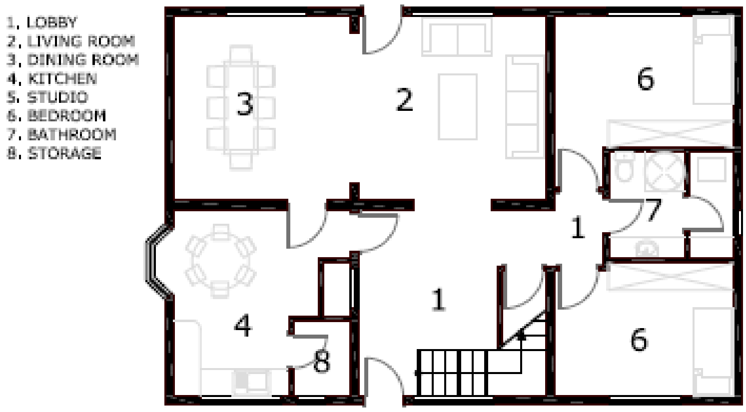


Fig. 6.3 - B. Family House, Timisoara, M. Mutiu arch. Ground Floor Plan

This single-family house was built in Timisoara, Romania, in 1999 [3,4]. The structure combines steel shear "wall stud" made of C shaped cold-formed profiles placed at 600 mm intervals with corresponding floor and has a timber roof framing as shown in figure.

The fastening solution is based on self-drilling self-tapping screws of 5.5 mm diameter for most of the connections, and in a few special cases, classic bolts.

The thickness of the structural walls is 150 mm. In order to provide load bearing capacity against horizontal loads, bracing straps are used on both sides of the wall panels. The thickness of the straps have to be small in order to ensure a flat surface for the finishing.

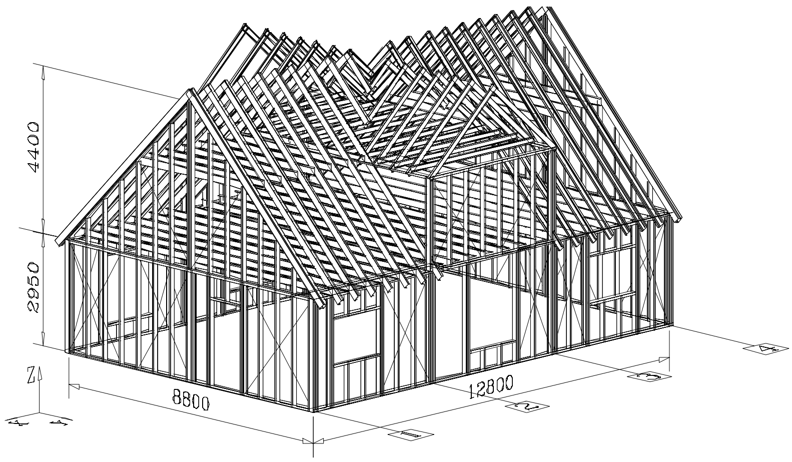


Fig. 6.4 - The main load bearing elements of the structure.

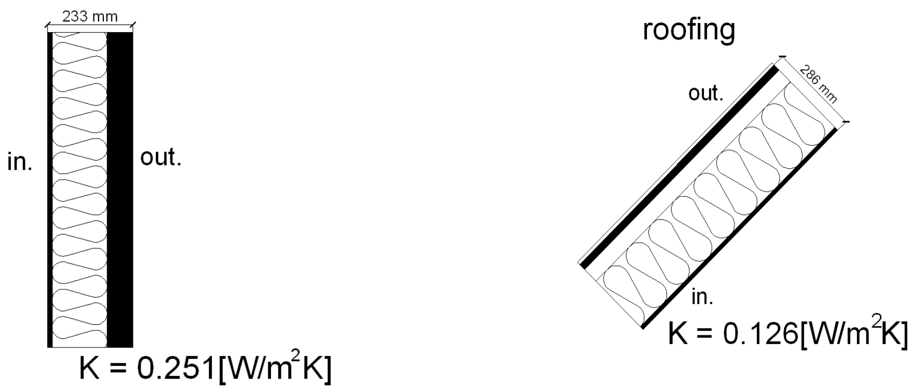


Fig. 6.5 – Layers used for roofing and cladding

The fastening solution is based on self-drilling self-tapping screws of 5.5 mm diameter for most of the connections, and in a few special cases, classic bolts.

The thickness of the structural walls is 150 mm. In order to provide load bearing capacity against horizontal loads, bracing straps are used on both sides of the wall panels. The thickness of the straps have to be small in order to ensure a flat surface for the finishing.

The dry floating-floor solution is used. The main joists are C profiles and the floor layers are: hardwood parquet (22 mm), phonic insulation (25 mm), wood decking (5 mm) and gypsum board ceiling (12.5 mm).

Adequate thermal and sound insulation is achieved by the use of high performance materials and by paying attention to the finishing details in order to ensure air tightness. The floating floor solution adopted was found to be very effective in reducing impact noise.

The following layers are used for roofing and cladding as shown in Figure:

- *Cladding (in/out):* gypsum board (12.5 mm); vapor barrier (0.5 mm); Lindab C150/1.5 joists; mineral wool (150 mm); Heratekta wood particles and cement (50 mm); plaster (20 mm);
- *Roofing (out/in):* asphaltic tiles, asphaltic bitumen membrane (3 mm); OSB board (20 mm); ventilation layer (50 mm); SOLFLEX aluminum layer; basaltic mineral wool (200 mm); timber rafter (250 × 50 mm/600 mm); vapor barrier (0.5 mm); gypsum board (12.5 mm).

Exterior finishing allows for either vernacular or modern architectural expressions. In this case, the owner's option was for a traditional look which was obtained by the use of traditional finishing materials throughout the house

The house is owner built, with the author being involved in supervising

First hand the building process on a daily basis.

The conclusions which emerged from this first steel framed house, probably one of the first at that time in Romania, were:

- The lightweight steel frame proved to be a viable choice both structurally and as envelope support.
- The envelope was completed successfully, and 12 years after completion, the house performs very well.


Fig. 6.6 - Skeleton of the structure and completed house.

Following is a cost analysis, the steel structure component is identified as representing around 20% of the total cost, the main costs being spent on finishing.

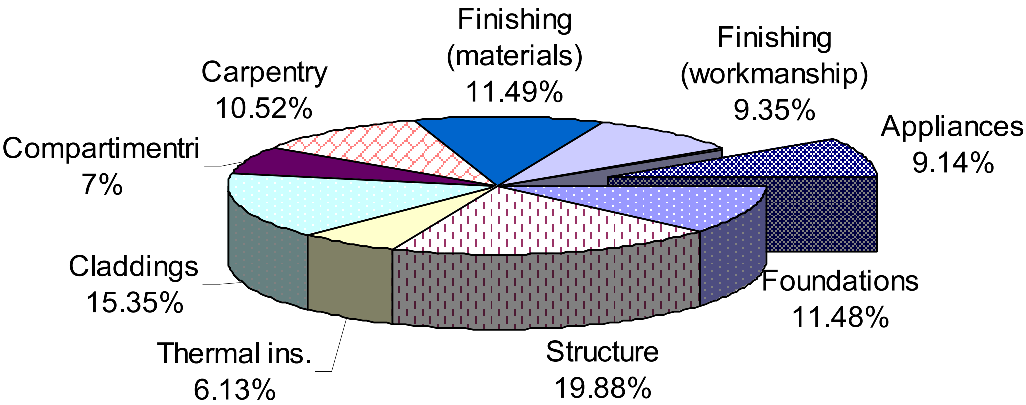


Fig. 6.7 - Cost distribution for the house – by components.

In the same time, some other aspects were noticed, related to floor layout and construction costs.

Indeed, as shown above, the lightweight steel frame, requires continuity of the load bearing walls and in so doing restricts the flexibility of the architectural layout.

The other conclusion concerns construction time. It became apparent that, the lightweight steel frame, requires a qualified construction labour force, capable to understand drawings and able to adjust on site stud dimensions. This was not the case and framing erection time was much longer than anticipated.

This finding promted us to consider the use of hot rolled steel framing for future residential applications.

6.3. DM Family House, Timisoara, Romania, 2008

Architectural Design

In 2002, the author started initial drawings for his family home, once a 572m^2 lot was purchased on the outskirts of Timisoara.

Being a corner lot, with North-South orientation, the layout slowly evolved towards an L-shaped configuration, which responded best under the given conditions to both functional requirements and privacy.

Fig 6.8 - DM House,Timisoara,2008- M.Mutiu, arch.

In terms of style, the most important problem to solve was to find an Architectural form, in tune with the landscape and close enough to traditional Or vernacular forms in order to anchor it firmly to the ground.

Indeed, the most important feature of the Western Plain is the sky, against which the silhouette of the houses are read.

Fig. 6.9 – Western Plane landscape

The choice to use a steep pitched roof was made therefore based on these considerations and in conjunction with the prevailing cottage like atmosphere which was sought from the beginning of the design process.

In the *puzsta*, such heavy roofs, were characteristic for some types of early houses before the 1718 Austrian colonization, as sown by this farmhouse in Hungary.

Fig. 6.10 - Typycal puzsta farm, Budapest tourist office

Elements of the „Arts and Crafts" movement were incorporated as well and the work of C.F.A Voysey was instrumental in finding specific architectural details, as the eye shaped dormers.

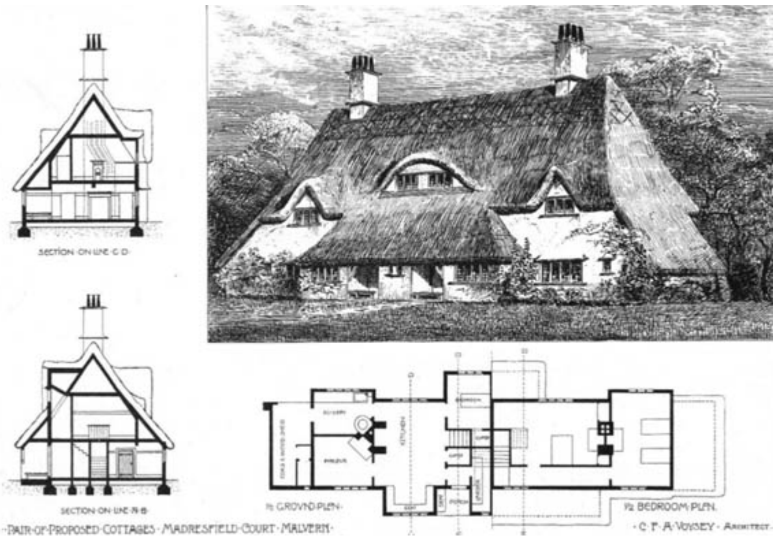


Fig. 6.11 - Voysey Two cottages, Madresfield Court, near Malvern Link

For practical reasons, in order to make the structural frame more efficient by reducing the spans, four columns were placed in the main room of the house, following the famous Cornaro Villa by Andrea Palladio.

Fig. 6.12 - Cornaro Villa by Andrea Palladio

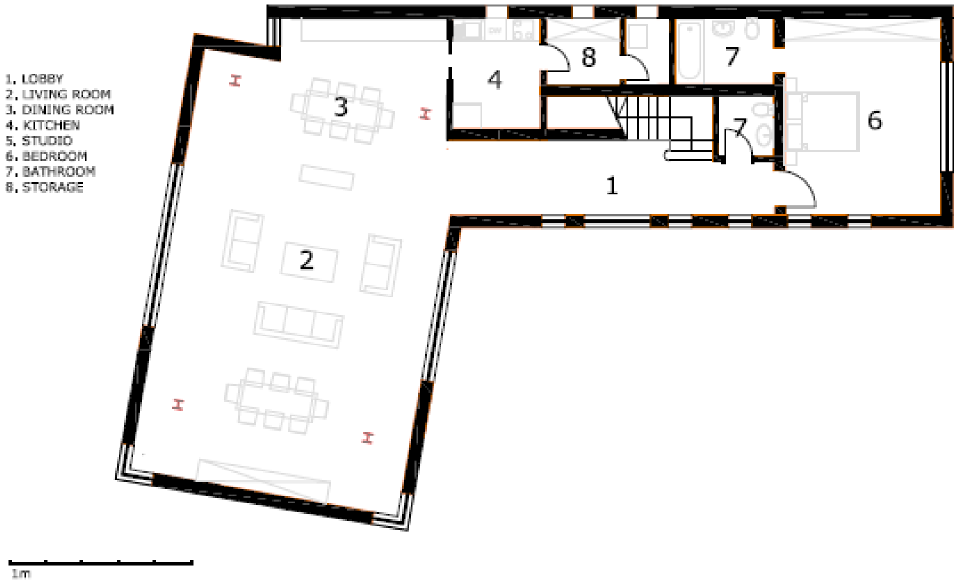


Fig. 6.13 – DM House,Timisoara,2008- M.Mutiu, arch. ground floor plan

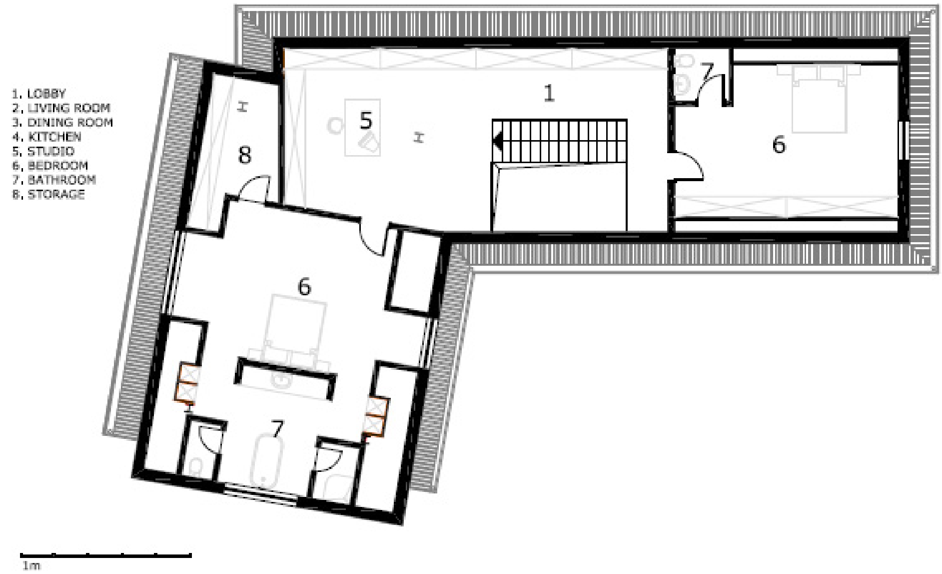
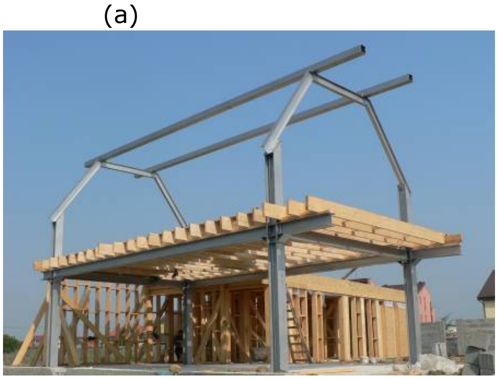


Fig. 6.14 – DM House,Timisoara,2008- M.Mutiu, arch., first floor plan

This single-family house was built in Timisoara, Romania, in 2008. The main structure consists of steel profiles, while the floors and roof are made of wood studs and rafters. The building combines modern and traditional materials and techniques, in order to obtain a typical Transylvanian village house.

Fig. 6.15 - DM house. (a) the main steel skeleton, (b) the steel skeleton with timber floor, (c) a general view, and (d) roof detail.

(a)



(b)

(d)

The following layers have been used for roofing and cladding:

- *Cladding (in/out):* gypsum board (12.5 mm); vapor barrier (0.5 mm); mineral wool (50 mm); vapor barrier (0.5 mm); ventilation layer (100 mm); mineral wool (100 mm); timber joists (50 × 200 mm/500 mm); OSB board (20 mm); Heratekta wood board (75 mm); plaster (20 mm)
- *Roofing (out/in):* tiles of wood, battens (50x50 mm); boarding (20 mm); SOLFLEX weather resistive barrier; OSB board (20 mm); ventilation layer (100 mm); vapor barrier (0.5 mm); basaltic mineral wool (200 mm); timber rafter (300 × 50 mm/600 mm); vapor barrier (0.5 mm); gypsum board (12.5 mm).

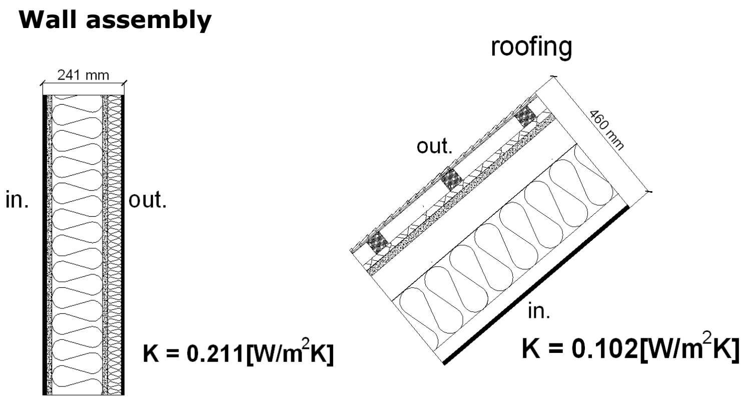


Fig. 6.16 - Layers used for roofing and cladding.

With regard to the sustainability of such a building technology, one could conclude it has an important environmental impact considering the types of materials used: steel for the skeleton, also steel for roof cover, highly processed wood (OSB) for wall boarding and so on. In the comparison between the "*Thin-Walled Cold-Formed*" (TWCF) house and the "*traditional*" one (the same house design with clay brick masonry and concrete), it was shown that—at least in this particular case—the steel framed house presents an important advantage over the traditional one. Of course, a lot of parameters (such as national or regional peculiarities, climatic zones or distance from the material distributors) may affect these results.

In terms of cost, assuming normal finishing costs, and excluding facilities; the price of a steel framed based house is € 395 + VAT/sqm, lower than a masonry house which is € 425 + VAT/sqm. This evaluation, based on 2008 prices, considers the initial costs only (*i.e.* excluding maintenance and operation). The speedier erection time is another advantage of steel framed solutions.

Fig. 6.17 – DM House,Timisoara,2008- M.Mutiu, arch., View

Fig. 6.18 – DM House,Timisoara,2008- M.Mutiu, arch., Courtyard view

Fig. 6.19 – DM House facade details

Fig. 6.20 – DM House, interior detail

6.4. P House, Timisoara, Romania, 2010

Architectural Design

The architectural design concept for this two storey house, located in Timisoara, Romania, was to make a cubic volume functional and to find a suitable plastic expression in a neighborhood characterized by non-descript architecture.

In rending the cube functional, the example of the Sobeck House was an inspiration from the beginning, even though the functional requirements at hand did not allow for a complete fluency of spaces.

Fig. 6.21 – P House,Timisoara 2010, M.Mutiu, arch.

As for the architectural expression, the work of Adolf Loss gave some important leads towards finding materiality. The choice of Loss was also prompted by some exquisite pieces of furniture to be displayed in the living room.

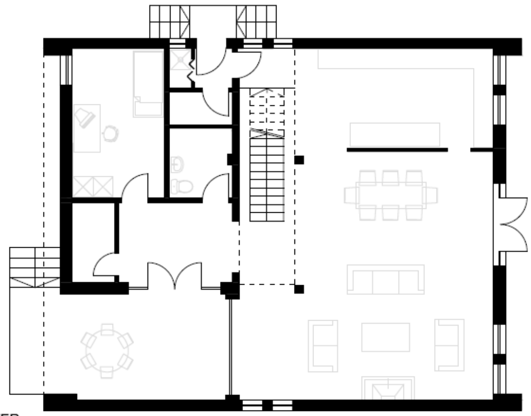


Fig. 6.24 - House P : Ground floor plan
M.Mutiu, arch.

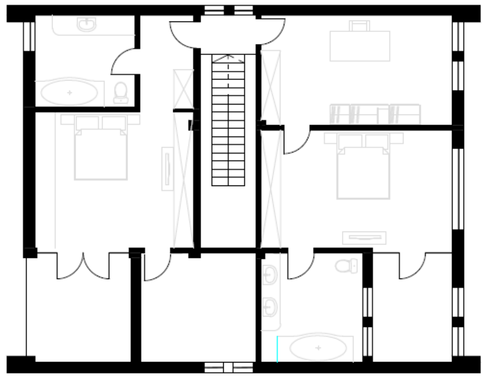


Fig. 6.25 - House P : Upper floor plan
M.Mutiu, arch

Fig. 6.22 Adolf Loos, Muller House

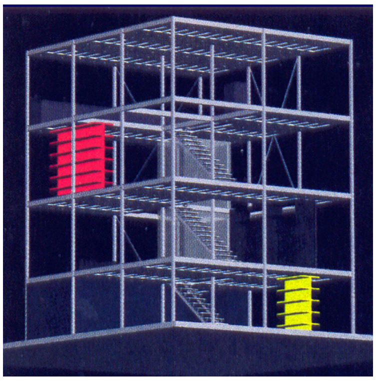


Fig.6.23–Sobek House- steel frame

This single-family house was built in Timisoara, Romania, in 2010. The main structure consists of hot-rolled steel profiles, while the floors and roof are made of steel deck, topped with lightweight concrete (600 kg/mc).

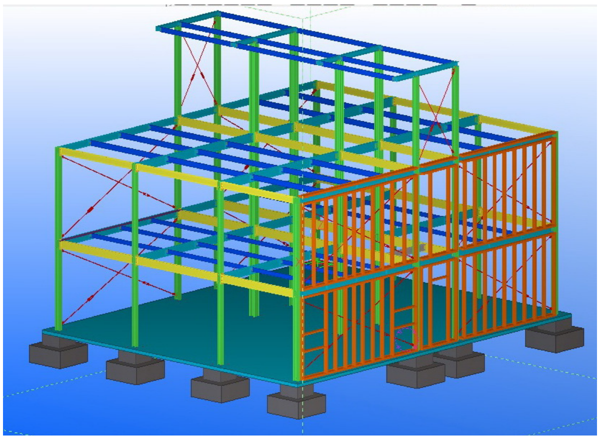


Fig. 6.26 – House P, 3D model view

Fig. 6.27 – House P, Steel Frame view

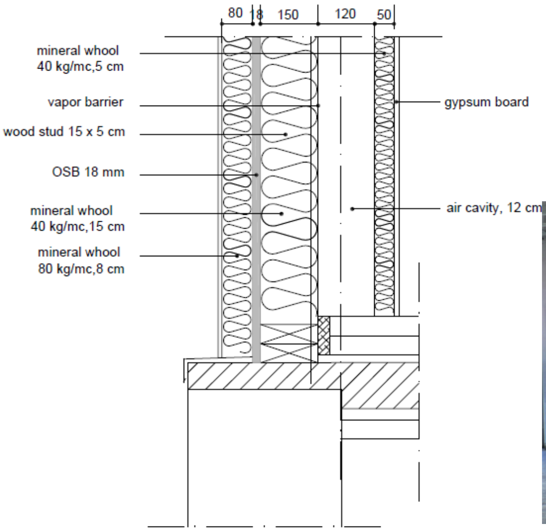


Fig. 6.28 – House P, envelope detail

Fig. 6.29 – House P, wall assembly

Fig. 6.34 – House P, stair case view

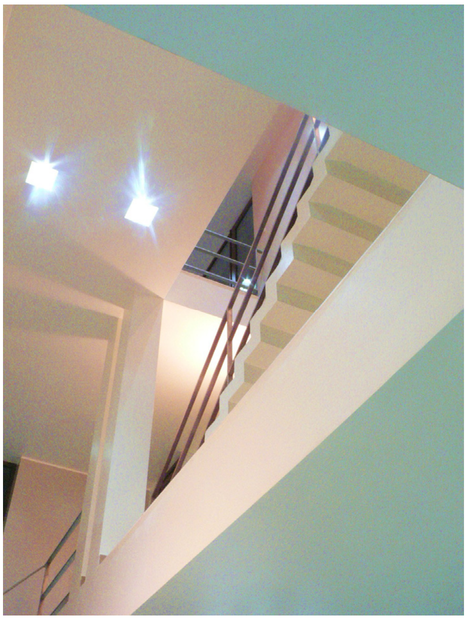


Fig. 6.30 - House P, interior detail

Fig. 6.31 – Adolf Loos- Muller House - Interior

Fig.6.32–HouseP,M.Mutiu,O.Gherman,arch.-Interior

Fig. 6.33 – House P,M.Mutiu,arch., back yard view

6.5. G House, Timisoara, Romania

Architectural Design

The architectural design of this bi-nuclear house to be built in Timisoara, Romania, in the coming year, is influenced by the expression of Steve Hermann's Californian architecture.

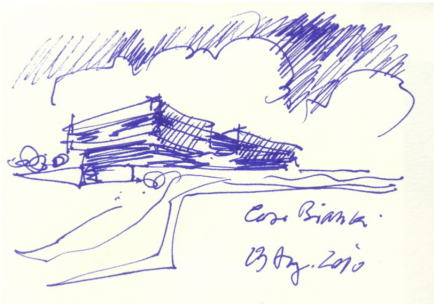


Fig.6.34 Casa G, Sketch

Fig. 6.35 - Steve Hermann, Glass Pavilion

Fig. 6.36 - G House - M. Mutiu, O. Gherman arch., Timisoara, Romania, 2011

This 500 m^2, upscale suburban villa incorporates some contemporary architectural elements such as cantilevered roofs and altogether a container like appearance.

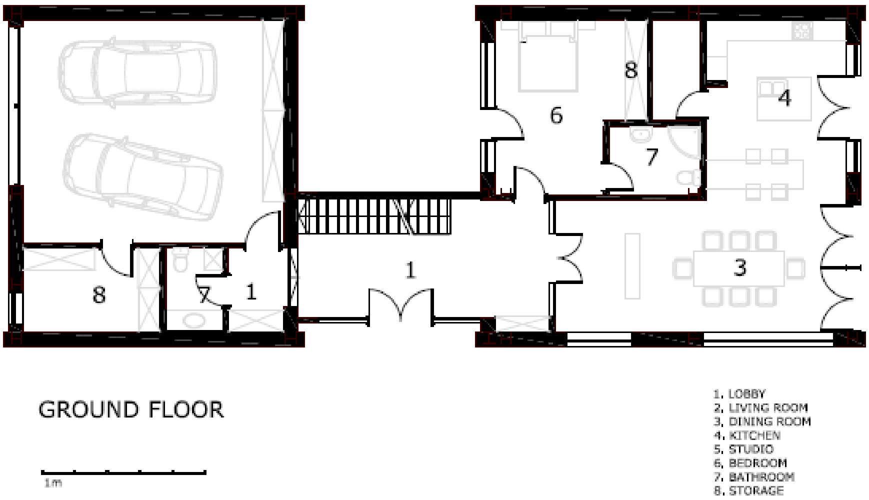


Fig. 6.37 - G House, G House - M. Mutiu, O. Gherman arch.,ground floor plan

The house has a bi-nuclear composition and the functional requirements are solved on three floors, the last being a partial one.

The ground floor spaces are open to the garden, at rear, with the garage situated under the building, at the same level with the entry. The second floor is composed of two main areas, a large living-room and two master bedrooms. A third floor is dedicated to two smaller children bedrooms and a play area.

The structural system is a mixed hot-rolled framing and timber, with the envelope finished in smooth plaster.

Work on the site is scheduled to start in 2012.

Fig. 6.38 - G House, G House - M. Mutiu, O. Gherman arch , upper floor plan

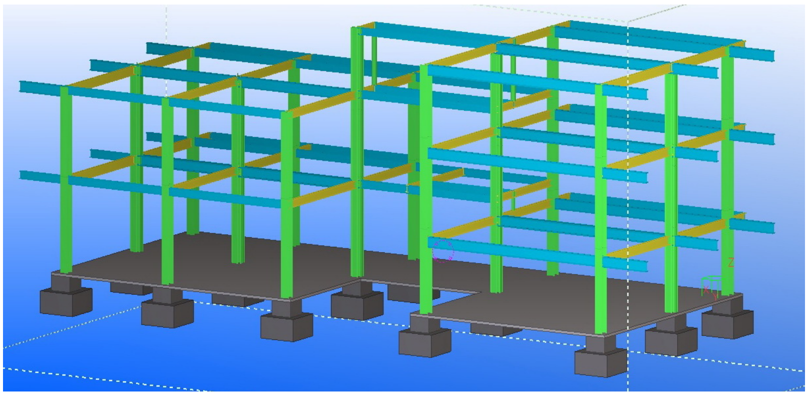


Fig. 6.39 - G House, 3D model view

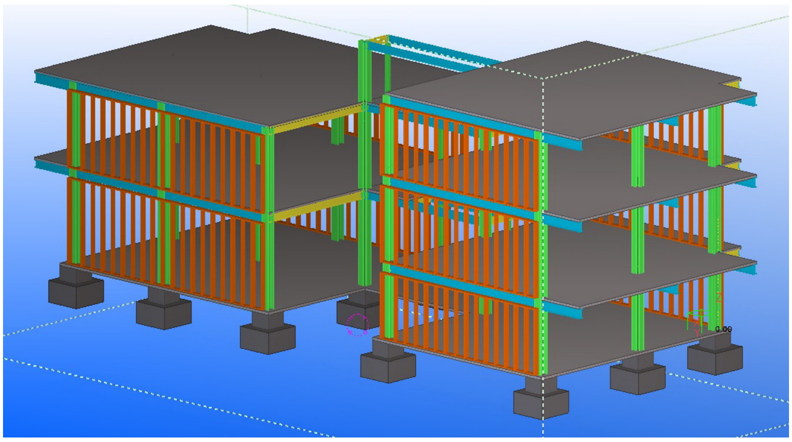


Fig. 6.40 - G House, 3D model view

Fig. 6.41 - G House - M. Mutiu, O. Gherman arch., Timisoara, Romania, 2011

6.6. Urban Villa, Timisoara, Romania, 2007

This building designed by the author, has a structure realized by Dubina et al. in 2007 in Timisoara, Romania. The keys for this kind of structure are built-in flexibility and energetic efficiency. The main structure is made of steel profiles with light floors. Column-free and free floor slabs are the optimum answer to allow users to optimally reconfigure internal areas, that means long-span solutions.

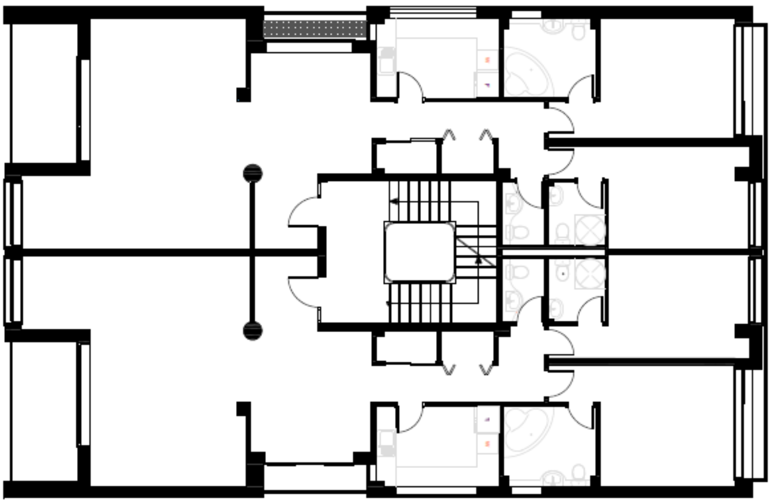


Fig. 6.42 – Arh. Mihai Mutiu - Urban Villa, 2007, current floor plan

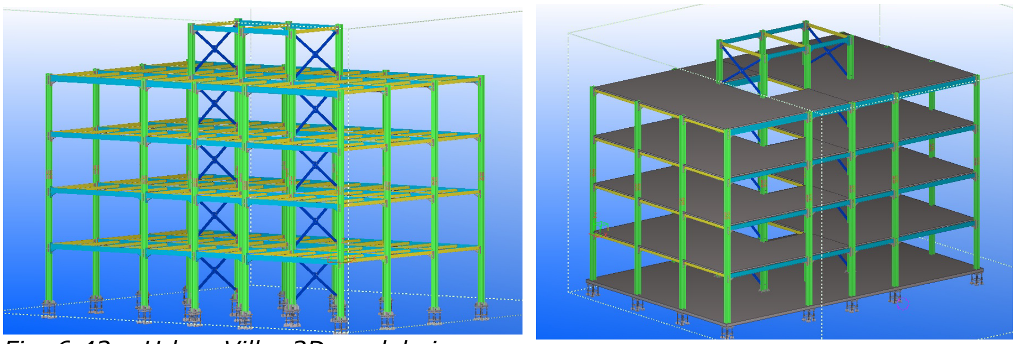


Fig. 6.43 – Urban Villa, 3D model views

Fig. 6.44 – Urban Villa, Steel frame view, Dubina et al. engineers

Fig. 6.45 Arh. Mihai Mutiu – Urban Villa – Main façade view

Envelope design

In building this high-end three story residential building, the builder/developer aimed at providing superior levels of comfort at a reasonable cost. With this in mind, the design was directed to fulfill three main objectives: (1) to minimize heat loss through the envelope; (2) to ensure high levels of physical well-being; (3) to equip the building with an energy saving heating system.

Fig.6.46 - Structure during erection and final view of the erected building

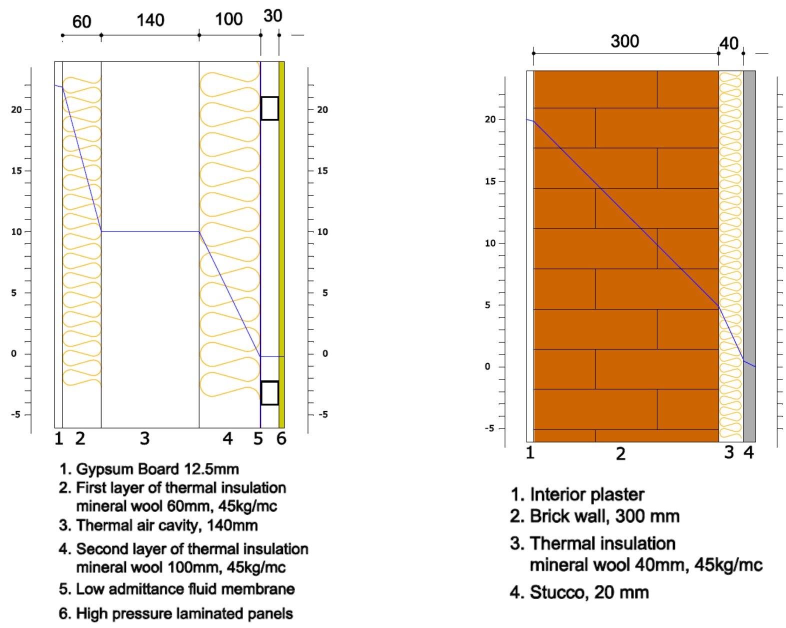
Timisoara is located in a moderate seismic risk region. In what concerns the climate, Timisoara city is located in the temperate continental moderate climate region which characterizes the Southern-Eastern part of The Panonic Depression. General climatic features consist of various and irregular weather conditions. The average annual temperature is of 10.6°C while the hottest month of the year is July (21.1°C). Being predominantly under the influence of North-western maritime air masses, the precipitations that occur in Timisoara are far more numerous than those from the Romanian Plain. The average 592mm annual amount is reached due to the rich May, June and July precipitations (34.4% of the total yearly amount).

Given the wide variations of seasonal temperature levels, as described above, and the cumulated effects of (1) overheating of the south and west facades in summer and (2) heat loss due to the wind-chill effect on the north / north-west sides of the facade in winter, special attention was paid first of all to the passive energy saving measures.

The envelope design was rationalised, as permitted by site conditions and functional parameters (Arghirescu et al. 2009):

- glazing was essentially restricted to the short facades [east and west], protected from the afternoon sun by deep loggias. Windows and exterior doors are thermpane with stratified wood frames;
- the long facades, facing North and South are mostly solid envelope, conceived as a thermal cavity system wall.

In Figure 6.47 are presented the actual layers for the cladding (in/out). The figure illustrates the importance of adequate insulation both as thickness and position in the wall assembly; the comparison was made with a brick wall. The combined effect of insulation thickness 60+100mm and the thermal buffer produced by the 140mm air layer, provides a high level of insulation for this climatic zone, both in summer and winter (K = 0.219W/m^{2}K). By comparison, a brick wall with 60mm insulation, has K = 0.406W/m^{2}K.



Thermal cavity wall: K = 0.219 W/(m^{2}K) Brick wall: K = 0.406 W/(m^{2}K)

Fig. 6.47 - Importance of adequate insulation

Figure 6.48 presents some pictures with the envelope during erection. The materials used in the building store moisture for a very limited period of time. Thermal insulation (basaltic mineral wool with density of 45kg/m^3) allows for constant vapour migration. In order not to trap the moisture in the rooms, the vapour barrier layer under the gypsum board was eliminated, allowing for the free vapour migration through the wall to the exterior. Given the gradual migration of vapour through the thermal cavity wall, conditions for condensation are practically eliminated.

Fig.6.48 - Envelope during erection

In order to ensure a high level of physical well-being for the occupants, the following set of conditions has to be kept under control:

- Control of average surface temperature of enclosing elements and room temperature;
- Control of relative humidity and room air temperature;
- Control of floor and roof temperatures;
- Control of air movement around occupants and room temperature;
- Control of acoustical influences.

The high level of thermal insulation combined with the moisture control benefits of the thermal cavity wall, address in a satisfactory manner the set of control measures enumerated above.

Ambiental measurements

Measurements were taken at the beginning of 2009 over a period of about two months (January and February), the coldest for this location, considered as indicative for the whole period in which the building is heated (see Table 6.1).

Two sets of temperature reading sensors were placed on the North and South facades of the building, in order to measure the interior, the wall cavity and the exterior temperatures. The positions of the sensors correspond to the living room area of the apartments, with a volume of approximate 120m^3. It has to be added that at the time the measurements were taken, the apartments were not occupied and, as a result, the contribution of human produced humidity in the room was not present.

TABLE 6.1. Northern facade measurements

Reading Hour	Date	Temperatures			Δ	Exterior Humidity (%)	Interior Humidity (%)	Interior Adjusted Humidity (%)
		T_{ext} (⁰C)	T_{tc} (⁰C)	T_{int} (⁰C)				
08:00	15.01.2009	-0,6	+10,1	+22,5	23.1	93	12	45-55
07:30	16.01.2009	-1,2	+8,7	+21,5	22.7	93	23	45-55
07:50	17.01.2009	-6,0	+7,9	+21,5	27.5	93	18	45-55
08:22	19.01.2009	+2,8	+10,5	+21,1	18.3	66	24	45-55
07:50	20.01.2009	+3,1	+12,0	+21,3	18.2	51	26	45-55
08:00	22.01.2009	+10,0	+16,0	+21,9	11.9	77	33	45-55
24:00	27.01.2009	+6,8	+16,3	+21,3	14.5	76	34	45-55
08:00	29.01.2009	+2,3	+13,0	+20,2	17.9	72	34	45-55
07:50	30.01.2009	+0,3	+9,5	+19,5	19.2	68	26	45-55
07:30	09.02.2009	+3,0	+12,7	+19,8	16.8	71	33	45-55
08:00	16.02.2009	-3,1	+7,1	+19,6	22.7	88	22	45-55
07:30	18.02.2009	-1,6	+7,8	+19,7	21.3	81	22	45-55
08:00	20.02.2009	-6,7	+3,1	+21,1	27.8	90	22	45-55
07:50	21.02.2009	-6,4	+5,8	+21,4	27.8	92	2	45-55
07:30	22.02.2009	-4,0	+7,5	+22,4	26.4	93	2	45-55

As Table 6.1 shows, moisture content in the building, during the heating season tends to be low, as long as no fresh air supply is provided. During the heating period, humidity levels in the building rise to 30-34% after short natural ventilation periods. When occupied, the humidity level is adjusted to reach 45-55% at 20°C, through natural ventilation, human produced humidity and/or with the help of humidifiers if required. It becomes evident that by removing the vapour barrier under the gypsum board, vapour migration through the envelope is accelerated. This factor combined with the mineral wool characteristics (of not storing moisture) are the key elements for moisture control.

The wall cavity has been continuously monitored. After two winter seasons with high variations in temperature and humidity, no particular problems were recorded.

The heating system

From technical point of view, the chosen solution is trying to make use of the energetic performances of the building, not only by means of production and distribution, but also by another parameter, i.e. the heating time, because it is very important to heat up only what we need and when we need.

The technical solution consists in the production of the thermal agent in a gas heated boiler and, in the same time in a CHP (combined heat and power unit). The distribution is made exclusively through the interior of the building, and the dispersion of the heat is done by convectors placed in the ceiling, which ensure a massive heat exchange (heating or cooling), in a short amount of time.

The usage of the CHP unit, which simultaneously produces hot water at 90°C and electricity, leads to a substantial reduction of costs, as the in-house produced electricity is cheaper than the electricity available from the distribution network. The hot water is stored in a tank, that can use thermal agent from the boiler/ CHP/ boiler + CHP/ solar panels/ heat pump/ electrical.

Some areas in the vicinity of the windows or the floors in the bathrooms are fitted with an intelligent electrical heating system, integrated in the floor. This has the advantage of being cost efficient, safe in exploitation, flexible in configuration, and can be controlled via the internet.

Evaluation of environmental impact

On the following the environmental impact for the block of flats is presented, performed at the level of construction stage only. The analysis was performed using the *SimaPro* software, a general and comprehensive tool, widely used in environmental design and LCA, which uses the *Ecoinvent* database. As mentioned before, in the analysis were included the material production and construction stage. The inventory analysis has been done according to the system boundary conditions. According to this, several aspects were considered:

- no finishing were taken into account (for example wall painting, the floor finishing, doors, windows and electrical or heating system);
- the transportation was not taken into account;
- the domestic use (water/gas/electricity use) of the building was not accounted for;
- the energy used for construction purposes (such as cranes and other technological machinery) were not integrated in the comparison.

It is to be noticed that due to the lack of information for the Romanian processes and materials, the mean European values were used for the inventory instead.

For the environmental impact calculation of the building, the input materials have been considered according to the constructive elements: (1) exterior walls; (2) interior walls; (3) intermediate floors; (4) terrace; (5) infrastructure.

In order to have an easier input of construction materials in the LCA tool, there have been computed average values for the weight of materials. These have been estimated for each type of constructive element as follows: the total weight of materials (resulted from the material lists) was divided to the total area of constructive element (in sqm). In this way, the final result represents an aggregate average per square meter of constructive element. This represents in fact the inventory analysis.

The following figures present the environmental impact by considering the above input data for construction phase but disregarding the materials and processes according to the boundaries described previously. All the results are given in "Eco-indicator points" (Pt) (Eco-indicator 99, 2000), which express the total environmental load of a product or process, based on data from a life cycle assessment, in order to have unitary and comparable outcomes. The method used for impact analysis is Eco-indicator'99.

Figure 6.49 presents the impact for the block of flats for the construction process ranked per constructive elements. The major impact corresponds to exterior walls and infrastructure. These constructive elements are high consumers of resources, but also have a great impact on human health.

Figure 6.50 presents the impact deduced only for construction stage. One could realize that for the structure the major impact comes from fossil fuels, as these resources are used for the fabrication of building materials at all levels. Also, important values of impact are recorded for inorganic respiratory emissions and eco-toxicity.

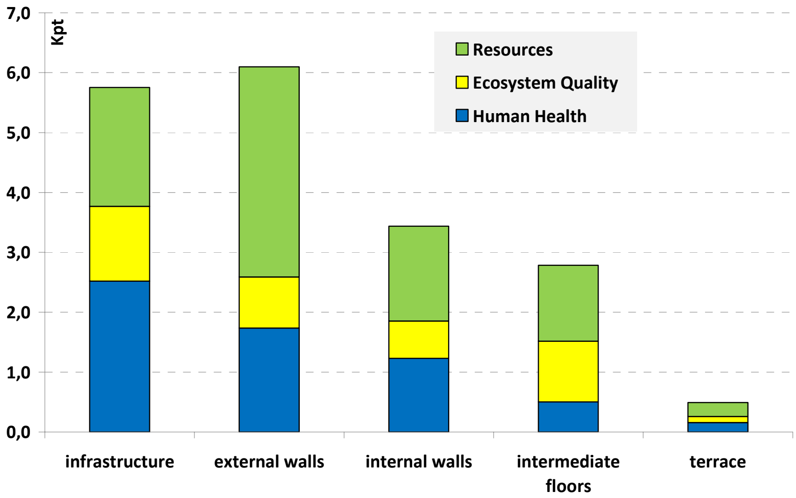


Fig.6.49 - Environmental impact per constructive element

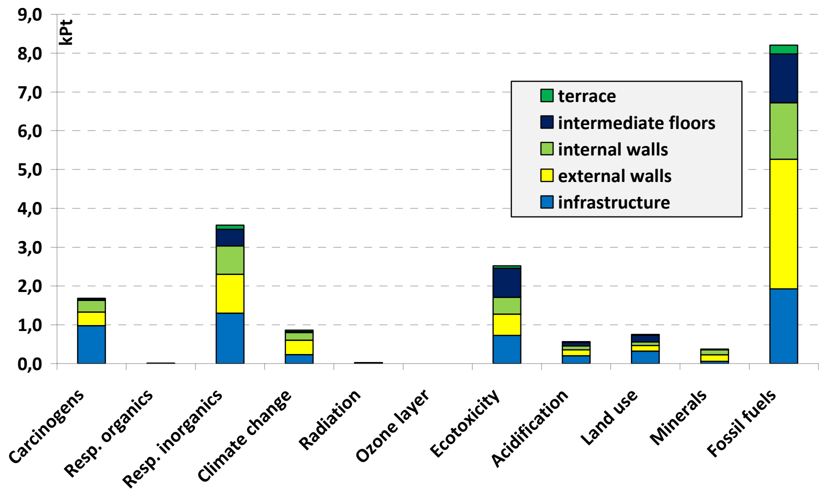


Fig.6.50 - The environmental impact for the block of flats (weighting)

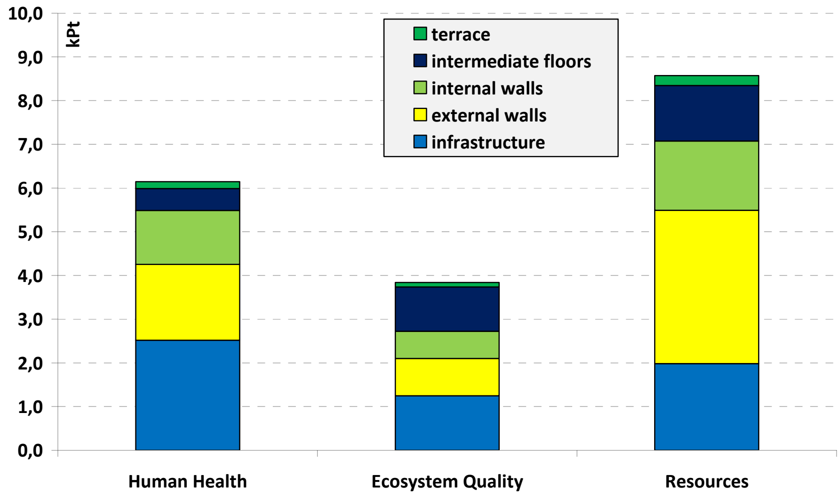


Fig.6.51 - The environmental impact for the block of flats – single score

The results presented above on impact (or damage) categories are aggregated into a single score, leading to an overall score of 18560 points.

Finally it can be observed that the major impact corresponds to exterior walls, followed by the infrastructure and interior walls. These constructive elements are high consumers of resources but also have a great impact on human health.

Conclusions

The building represents a complete sustainable technology of high performance thermo-energetic materials used for cladding and finishing. It enables to obtain flexible partitions and allows for further up-grade, easy modifications and/or development.

The steel main frame allows for: (1) high design and construction safety standards; (2) larger spans; (3) layout flexibility; (4) faster fabrication and erection times; (5) high solution diversity for flooring and envelope.

In what concerns the physical well-being for the occupants, a set of parameters can be kept under control: (1) inside average temperature; (2) relative humidity and room air temperature; (3) air movement; (4) acoustic insulation.

In the second part, the authors perform an environmental impact analysis for the block of flats, for the construction stage only. The analysis shows that the major impact corresponds to exterior walls, followed by the infrastructure and interior walls. These constructive elements are high consumers of resources but also have a great impact on human health.

6.7. C House

Architectural Design

In recent years, steel framed houses have become a choice for house construction in many European countries, including Romania. Compared with traditional solutions, the properties of the light-gauge steel skeleton can be exploited to take both technical and economical advantages from lightness of structures, ease of prefabrication, speed of erection and enhanced quality.

In what concerns the sustainability of such systems, one may think that they could have an important environmental impact, taking into account the types of materials used: steel for the skeleton, also steel for roof cover, highly processed wood (OSB) for wall boarding and so on.

This is the reason why a comparison between the "traditional house" and the "Thin-Walled Cold-Formed" (TWCF) house is welcome in the domain of sustainability. In this perspective, the present work presents a comparison, made for a common family house. Similar studies (Santos et al. 2010) showed through LCA studies that the environmental performance of light-weight steel houses is greater than that of traditional ones.

The house under investigation represents a private single-family house, built in TWCF solution, in 2005 in Ploiesti, Romania (Ungureanu & Dubina 2006). There are two main characteristics of the built house, namely the lightweight-steel framing and the architectural solution constrained by the site shape.

From the architectural point of view, the main challenge of the project was to fit the house on an irregularly shaped lot of only 168 m^2. The resulting cube-like building measured at the end 84m^2 of built area on each of the two floors. Due to the proximity of the buildings on the adjacent properties, the next difficulty consisted in finding the balance between the right amounts of views, natural light and privacy. Because the building seats on the property limit, it was impossible to provide window openings on that side. This was also one of the reasons for using a single sloped roof, the resulting height of the building ranging from 9m to 10.5 m. Each floor has approximately 2.75 m height with a roof slope of 30°. Two skylights located above the staircase and the hallway, were placed in order to provide a light shaft, in order to enhance the central part.

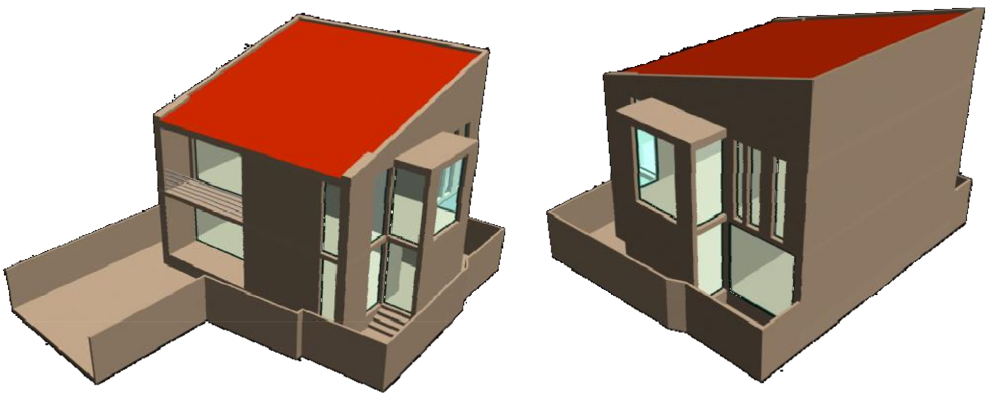


Fig.6.52 - 3D views of C family house.

Lower floor plan: 1. dining room; 2. kitchen; 3. living room; 4. den; 5. laundry; Upper floor plan: 6. master bedroom; 7. library; 8. bedroom; 9. dressing; 10. bathroom; 11. logia

Fig.6.53 - C house,M. Mutiu,arch., Floor plans

Description of TWCF system

The structural skeleton is made of light-gauge C shaped profiles (C150/1.5) spaced at intervals of 600 mm, with a thickness of 1.5 mm, fixed with 4.8 mm diameter self drilling screws. The height of the cross-section of profiles is 150 mm, dimension that governed the thickness of the walls. In order to withstand horizontal actions and to provide stiffness and strength the walls were stiffened using 12 mm thick Oriented Strand Boards (OSB) provided on both sides of the structural walls.

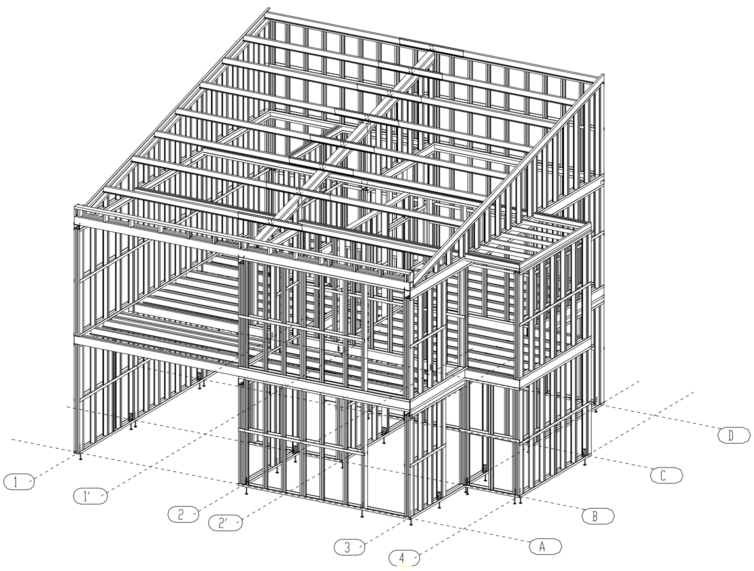


Fig.6.54 - Steel skeleton of the structure.

The load bearing beams in the slab are C200/1.5 profiles disposed at 600 mm intervals, this distribution resulting from the condition of controlling the vibrations of the floor rather than from strength conditions. Roof purlins resulted as Z150/1.5 profiles spaced at intervals of 1200 mm. The floor diaphragms were designed to be based on the same principle of covering with OSB. No concrete was used on the slab.

The isolated foundations under columns were linked by foundation beams. The floor at ground level (concrete slab of 10 cm) was cast over a bed of dense soil and a layer of compacted gravel.

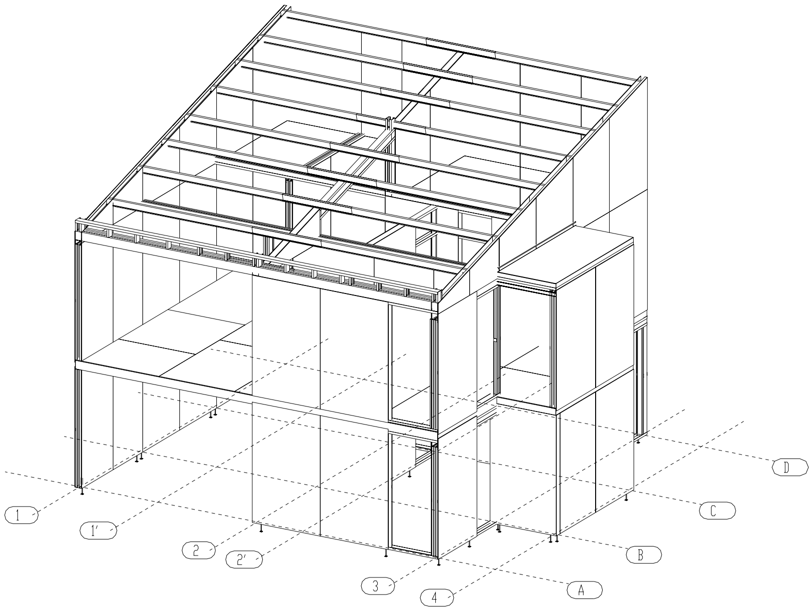


Fig. 6.55 - Skeleton with structural OSB sheeting.

Figure 6.56 shows the structure in two different stages: (a) the finished steel skeleton and (b) the steel skeleton stiffened by load bearing OSB panels.

(a) the finished steel skeleton *(b) the steel skeleton together with all load bearing OSB panels attached*

Fig.6.56 - The structure during construction.

Fig.6.57 - C family house – completed house.

Description of Traditional Romanian dwelling

In order to have a real environmental impact comparison, a masonry structure has been designed following the above-described architectural plans (Ciutina et al. 2009; Ciutina & Ungureanu 2009). Due to differences of wall thicknesses used in the two solutions, the main preoccupation was to obtain the same inside volume for all rooms.

The design considers the same location of the building and the same imposed and climatic loadings. The resulted structural system is composed by masonry walls of 25 cm, concrete floor, continuous foundations and timber roof structure covered with ceramic tiles.

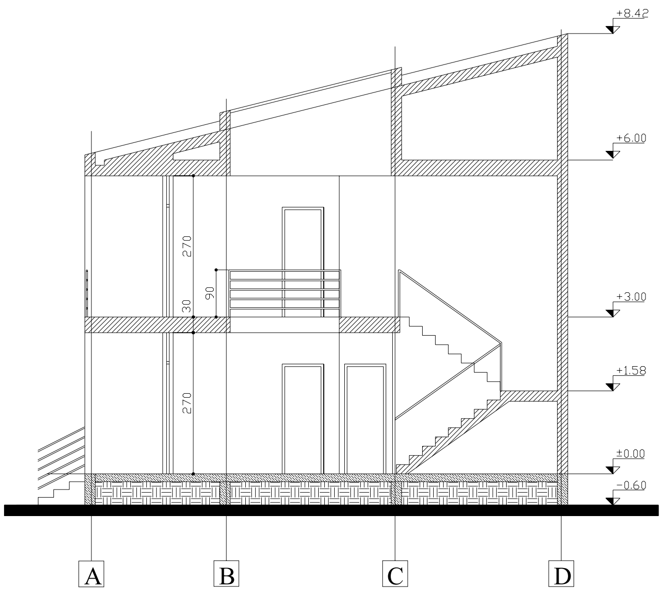


Fig.6.58 - Vertical section with the masonry/concrete structure.

Structural design

TWCF structure

General data

The structure is designed considering the climatic and seismic conditions of the city of Ploiesti, Romania. The loads used for the design of the structure were taken according to Romanian codes, actually aligned to relevant Eurocodes.

The self weight of the structure was evaluated at: 0.45 kN/m^2 for the roof, 0.70 kN/m^2 for the slab, 0.60 kN/m^2 for exterior walls and 0.20 kN/m^2 for internal walls. The other loading conditions were determined according to the Romanian standards. Imposed load on the slab was taken as 1.50 kN/m^2, snow load on the roof as 1.20 kN/m^2 and wind load on the surface exposed to maximum pressure as 0.40 kN/m^2.

The earthquake design of the building was done for a peak ground acceleration (PGA) of 0.25g allowing no reduction of the seismic action by choosing a behavior factor q = 1. This condition is required by national regulations, which do not allow for reduction of seismic forces in case of light-gauge steel structures; the rules being independent of the structural scheme.

The design of structural elements (columns, beams) was made according with EN1993-1-1, EN1993-1-3, EN1993-1-8 and Romanian seismic design code P100-92, both for ULS and SLS. To control the floor vibrations, a deflection of L/350 was considered reasonable for a family house.

The structural skeleton is made of light-gauge C shaped profiles framing. Columns are pinned at the base on both directions. In order to withstand horizontal actions from wind and earthquake and to provide stiffness and strength, the walls were stiffened using 12 mm thick Oriented Strand Boards (OSB) provided on both sides of the structural walls. The floor diaphragms were designed to be based on the same principle of covering with OSB.

Seismic design

In what concerns the seismic response, the performance of shear walls is crucial. Test results of full-scale wall panels, made by cold-formed wall-stud skeleton and different cladding arrangements, commonly used in residential buildings, tested in the Laboratory of Steel Structures of the "Politehnica" University of Timisoara, Romania (Fülöp & Dubina 2004a,b), have been used as reference values for checking the available shear strength of walls.

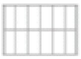
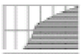
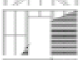
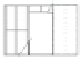
For the 3D analysis, the rigidity induced by the sheathing has been replaced by equivalent cross bracings and considering the frame to be pinned. Rigidity criteria and test results on wall specimens have been used to calibrate the area of equivalent braces. The structure is subjected to torsion during an earthquake because the walls on axes 1 and D are fully sheathed, while the ones on axes 3, 4 and A accommodate all the openings. In these conditions, from the point of view of earthquake, the most critical wall panel is the one from axis A on the ground floor. The maximum shear force in this wall was 43 kN (12.8 kN/1m).

The masses were computed from the earthquake combinations (1 × self weight + 0.4 × live load + 0.3 × snow load) according to Romanian standards in 2004. The first three vibration modes of the structure have been simulated using FE analysis, and the corresponding periods of vibration are: T_1 = 0.38s, T_2 = 0.35s and T_3 = 0.26s.

Design assisted by testing on full-scale wall panels

For a proper design of cold-formed steel-framed houses in earthquake regions, the behavior of the shear walls has to be known. Besides the structural walls, the behavior of a house is influenced, at least in the early stage of the shaking, by the non-structural elements which usually is not accounted for in the design. The non-structural finishing elements have a structural contribution that changes the vibration modes and the damping properties of the structure.

Description of wall specimens

Series	Opening	Bracing	Exterior cladding	Interior cladding	Testing method	Loading velocity	No. test
O		–	–	–	Monotonic	1	1
I		–	Corrugated Sheet LTP20/0.5	–	Monotonic Cyclic	1 6–3	1 2
II		–	Corrugated Sheet LTP20/0.5	Gypsum Board	Monotonic Cyclic	1 6–3	1 2
III		–	–	–	Monotonic Cyclic	1 3	1 1
IV		Door	Corrugated Sheet LTP20/0.5	–	Monotonic Cyclic	1 6–3	1 2
OSB I		–	10 mm OSB	–	Monotonic Cyclic	1 3	1 1
OSB II		Door	10 mm OSB	–	Monotonic Cyclic	1 3	1 1
Total number of specimens							15

Tab. 6.2 Description of wall specimen

A large experimental and numerical investigation has been carried out at the "Politehnica" University of Timisoara, along several years, in order to evaluate and characterize the behavior of this type of structures (Dubina 2008). First, the stiffness, resistance and ductility of cold-formed steel shear walls have been evaluated via laboratory tests and numerical simulations (Fülöp & Dubina 2004a,b). Afterwards, the main modal characteristics have been determined in three subsequent stages of construction and analyzed in order to evaluate the seismic performance of the building as a whole and used to quantify the influence of the non-structural elements which are not accounted for in the modeling (Dubina 2006).

One of the problems arising during the design of such a structure is the evaluation of the load bearing capacity and of the rigidity of the sheathing system of walls and slabs. The case of the slabs can be covered by general provisions (ex. some detailing conditions) due to the low level of stresses, but the realistic analysis for the walls is crucial. In this case extrapolation from existing experimental results on shear walls was the basis used for the evaluation of the load behavior properties. Walls with similar skeleton sheathed on one side using identical OSB panels (t_{OSB} = 10 mm), with similar fixing plan (i.e. 105 mm screw intervals) and the same diameter screws (d_{screw} = 4.2 mm) were previously tested monotonically and cyclically (Fülöp & Dubina 2004a,b). A particular attention was paid to the influence of the fastening system (Fülöp & Dubina 2006). The summary of the entire testing program is described in Table 6.2, while the testing set-up and a sample of results are shown in Figures 6.59 and Figure 6.60.

The tested panels were 2.55 m high, 3.6 m long and the ultimate load obtained from the test was F_{max} = 69.8 kN (or 19.4 kN/1m). The elastic rigidity of the panel was K_{ini} = 4197 kN/mm. The wall panels used (OSB I and OSB II) were sheathed on both sides with OSB and the corner details were strengthened in comparison to the tested case. The design capacity of the walls used for the construction has been evaluated to F_{des} = 17.6 kN/1m.

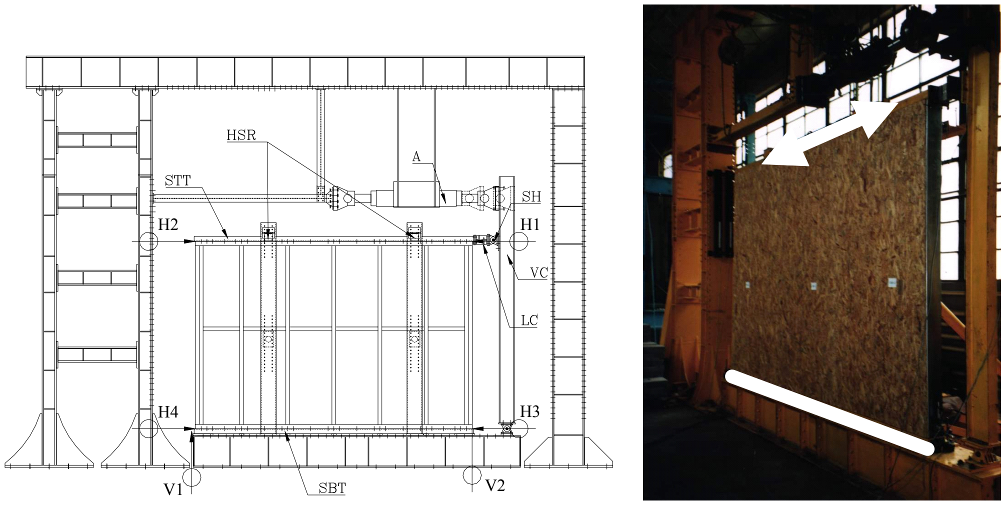


Fig. 6.59 - Experimental set-up.

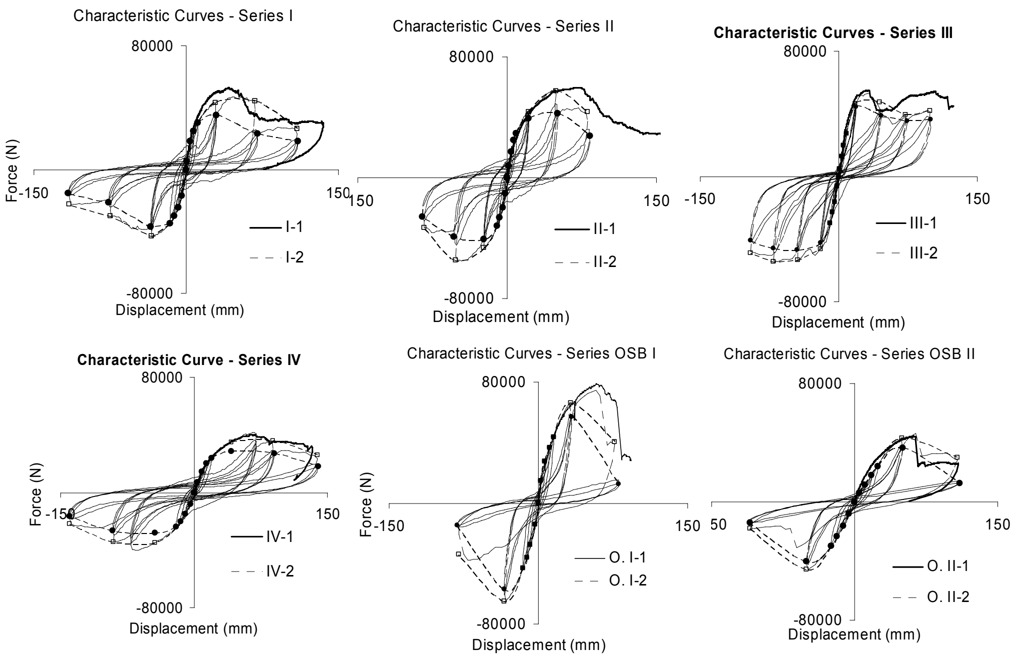


Fig.6.60 - Experimental curves.

Based on experimental results , a very simple method was applied to calculate the efficiency of shear wall panels. Due to the configuration of the structure, the analysis can be divided following the two principal directions, i.e. transversal and longitudinal ones (Fülöp 2003). In transversal direction it is considered that seismic action is resisted by the transversal shear walls, while longitudinally by the longitudinal shear walls.

The lengths of the shear wall panels that compose the analysed TWCF structure, for the ground and first floor, both on transversal and longitudinal direction are presented in Table 6.3.

Table 6.3. The lengths of the shear wall panels for the TWCF structure (in meters).

Transversal	**Axis 1**	**Axis 1'**	**Axis 2**	**Axis 2'**	**Axis 3**	**Axis 4**	***Total***
Ground floor	8.1	3.2	3.2	2.18	1.62	3.25	*21.55*
First floor	9.05	-	3.2	-	1.62	3.25	*17.12*
Longitudinal	**Axis A**	**Axis B**	**Axis C**	**Axis D**	**-**	**-**	***Total***
Ground floor	3.37	1.5	3.3	9.05	-	-	*17.22*
First floor	3.37	-	-	9.05	-	-	*12.42*

In a first step, the total mass of the structure is evaluated, at the level of the first floor and at the roof level, taken into account the loads and safety coefficients, considered for the special combination of seismic action:

$$\sum_{j=1}^{n} G_{k,j} + \gamma_I A_{E,k} + \sum_{i=2}^{m} \psi_{2,i} Q_{k,i} \tag{1}$$

where:

$A_{E,k}$ – Characteristic value of seismic action;

$\psi_{0,i}$ – Factor for combination value of the variable action *i*;

Q_i – 0.4 for snow load and live load.

It results: (i) the total mass at the floor level $M_{ground\ floor}$ = 23.07 t and (ii) the total mass at the roof level $M_{first\ floor}$ = 11.71 t. Accordingly, the total seismic force applied on the structure is:

$$S_e(T) = \gamma_I \cdot a_g \cdot \beta(T) \cdot g \cdot M = 1 \cdot 0.28 \cdot 2.75 \cdot 9.81 \cdot (23.07 + 11.71) = 262.72 \text{ kN} \tag{2}$$

Considering that the deformation is linear in regard with the height, the horizontal load is distributed to both levels as follows:

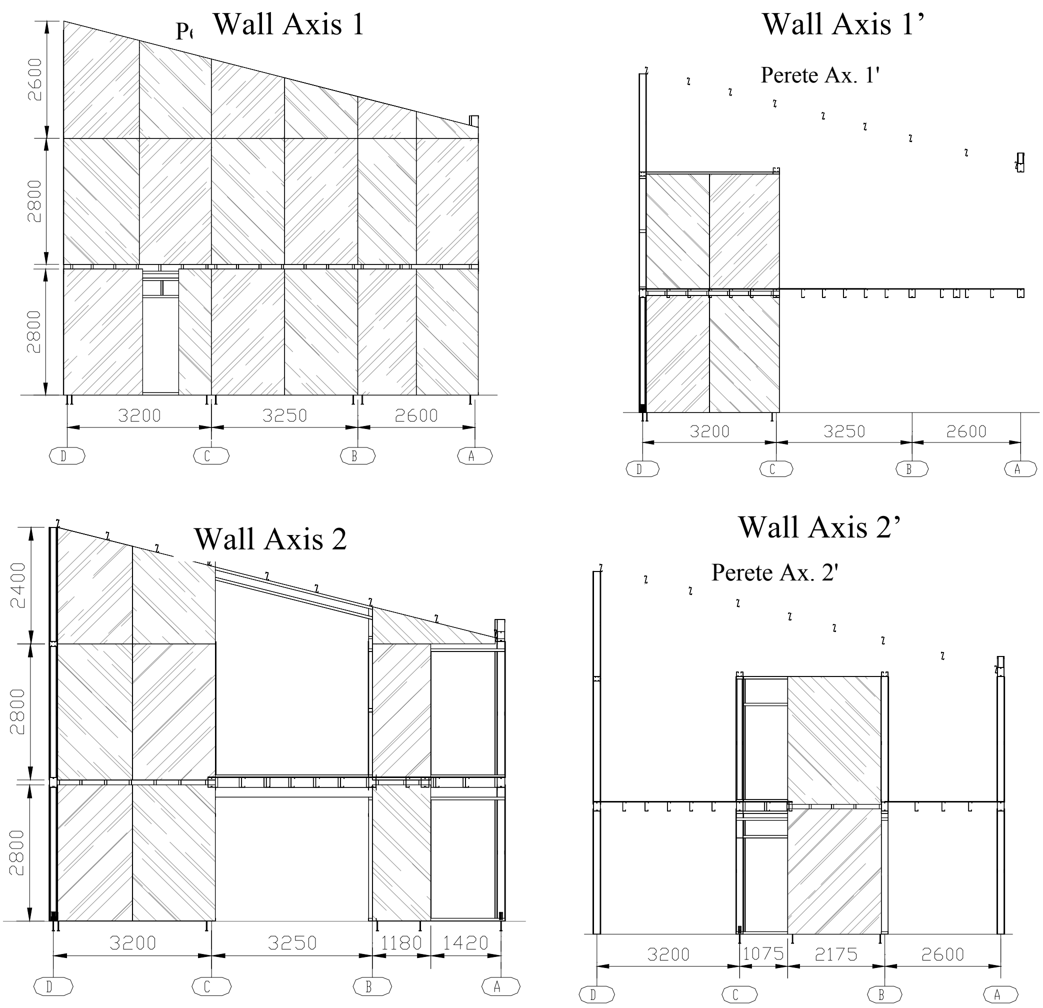
$$\begin{aligned} S_1 &= S_r \cdot \frac{z_1 \cdot G_1}{\sum(z_j \cdot G_j)} = 262.72 \cdot \frac{3 \cdot 23.07}{(3 \cdot 23.07 + 7 \cdot 11.71)} = 120.27 \text{ kN} \\ S_2 &= S_r \cdot \frac{z_2 \cdot G_2}{\sum(z_j \cdot G_j)} = 262.72 \cdot \frac{7 \cdot 11.71}{(3 \cdot 23.07 + 7 \cdot 11.71)} = 142.45 \text{ kN} \end{aligned} \tag{3}$$

The total seismic force corresponding to both levels are:

$$\begin{aligned} T_{ground\ floor} &= S1 + S2 = 262.72 \text{ kN} \\ T_{first\ floor} &= S2 = 142.45 \text{ kN} \end{aligned} \tag{4}$$

Based on experimental work, for the analysed shear wall panels the shear capacity under cyclic loadings was found of 69844 N (Fülöp & Dubina 2004a,b), which means for a length of 3.6 m of the tested panels an experimental reference capacity of 19.40 kN/m.

According to American code (AISI, 1998), for a similar shear wall panel, sheeted on one side (OSB 7/16" and self drilling screws No. 8 x 1in., placed at every 4 in.), the shear capacity is of 915 lbf/ft, i.e. 14.59 kN/m. The American code (AISI, 1998) allows to determine the shear capacity of shear walls with a ratio length / height smaller than ½. The shear capacity of such a shear wall can be obtained by multiplying the reference value of 14.59 kN/m by 0.6, which gives a shear capacity of 8.754kN/m. Considering the fact the walls of the analysed structure are sheeted on both sides, the shear capacity is doubled, becoming P_{calc} = 17.51 kN/m.



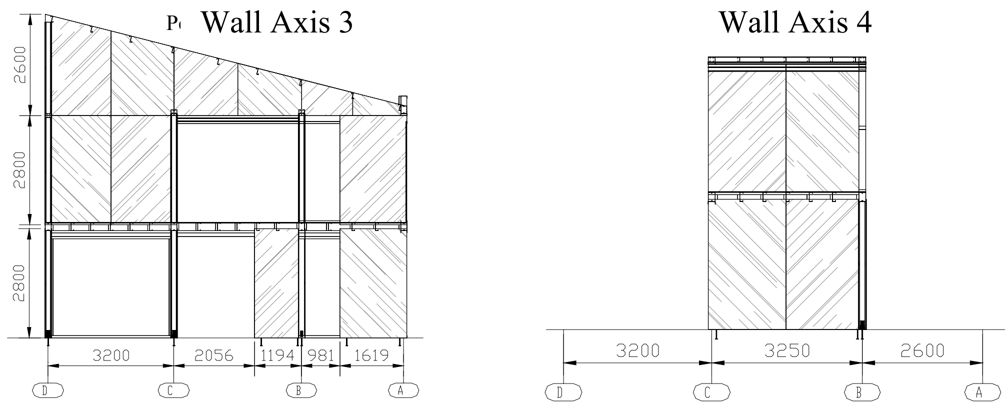


Fig.6.61 - The shear walls on transversal direction.

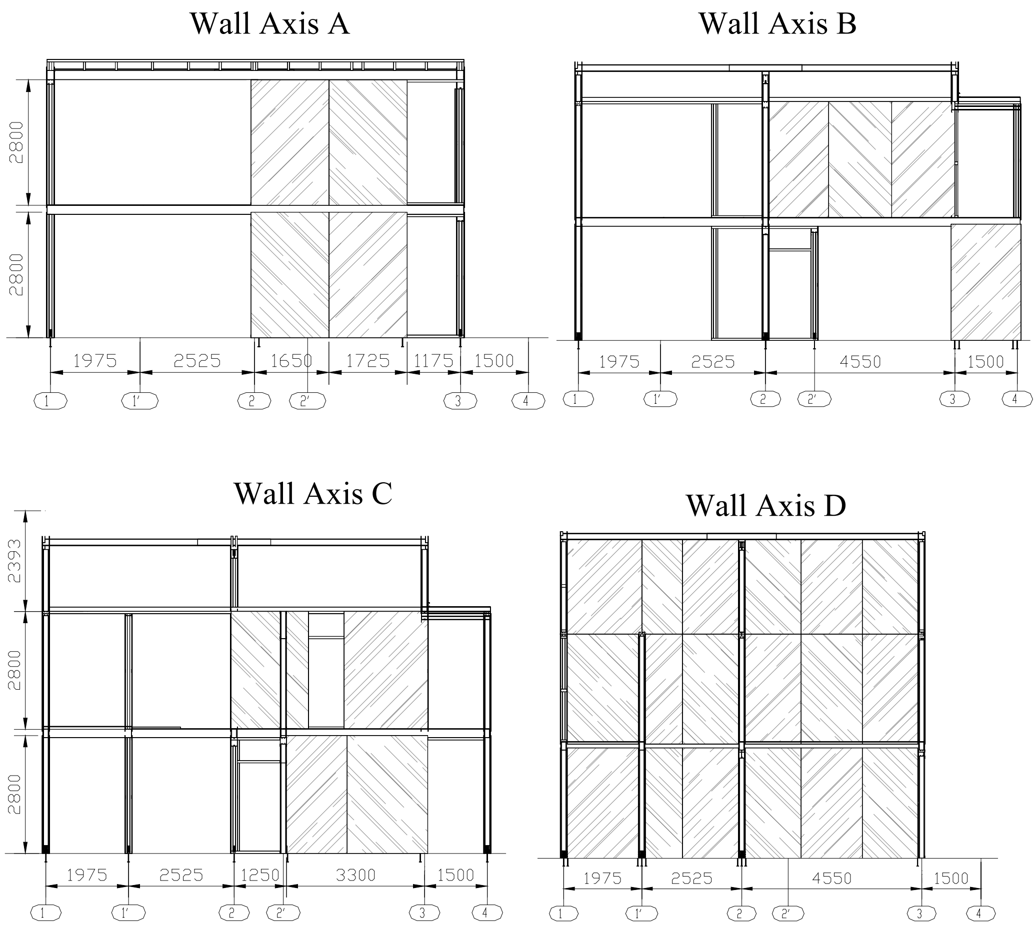


Fig.6.62 - The shear walls on longitudinal

Finally, the length of walls necessary to provide the shear capacity results as:

$$L_{ground\ floor} = \frac{T_{ground\ floor}}{P_{calc}} = \frac{262.72}{17.51} = 15.00\ m < 21.55m\ (transversal)$$

$$< 17.22m\ (longitudinal) \quad (5)$$

$$L_{first\ floor} = \frac{T_{first\ floor}}{P_{calc}} = \frac{142.45}{17.51} = 8.14\ m < 17.12m\ (transversal)$$

$$< 12.42m\ (longitudinal)$$

In-situ measurements

The project was a pilot one in Romania, where the building location is recognized as a high risk seismic zone, and for this reason the design procedure and the seismic performance of the structure have been confirmed by in situ tests.

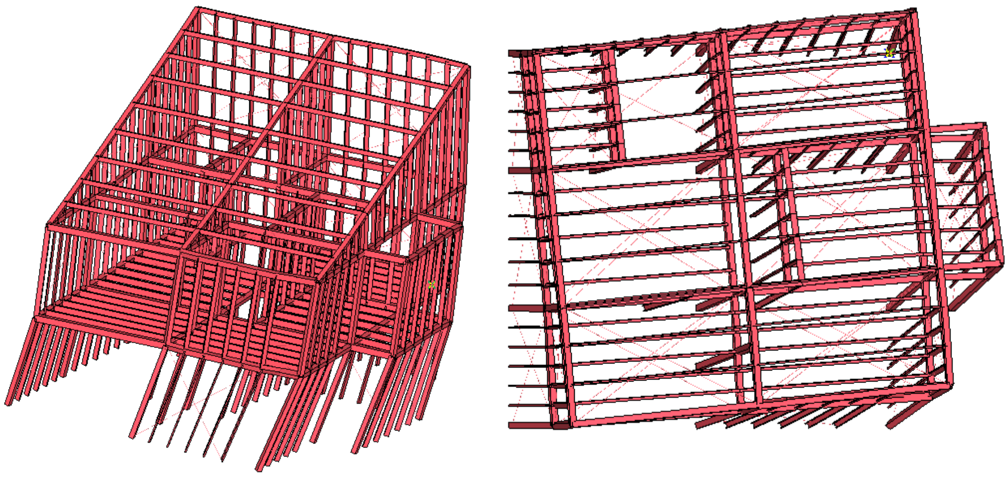
For that purpose, the dynamic properties for small amplitude vibrations of the building have been studied by direct measurements in three distinct stages of construction:

- Stage 1: only the self weight of the steel structure has to be taken into account;
- Stage 2: the steel skeleton together with all load bearing OSB panels fixed;
- Stage 3: the completed building with all finishes, before being handed over to the owner.

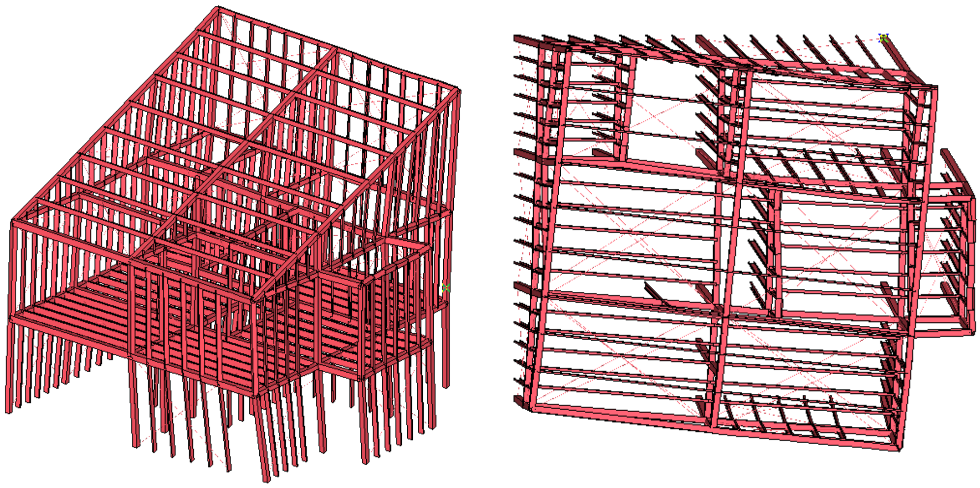
It has to be underlined that no live or snow load has been taken into account during measurements.

Before *in situ* tests the dynamic properties have been determined by FE analysis. The self-weight of the steel skeleton (i.e. excluding the trapezoidal sheathing) has been evaluated to 4600kg. The masses of the sheeting and finishing elements are M_1 = 700kg (Stage 1), M_2 = 4650kg (Stage 2) and M_3 = 25200 kg (Stage 3). In the earthquake design situation the mass of the structure is M_{design} = 32700 kg. Taking into account the contribution of these masses the vibration periods presented in Table 6.4 were predicted using FE analysis. Note that Stage 3 (i.e. the structure with finishing) differs from Stage 2 only from the point of view of the supplementary mass generated by the finishing; the stiffness contribution of the secondary and finishing elements has not been included in the modelling.

a)



b)



c)

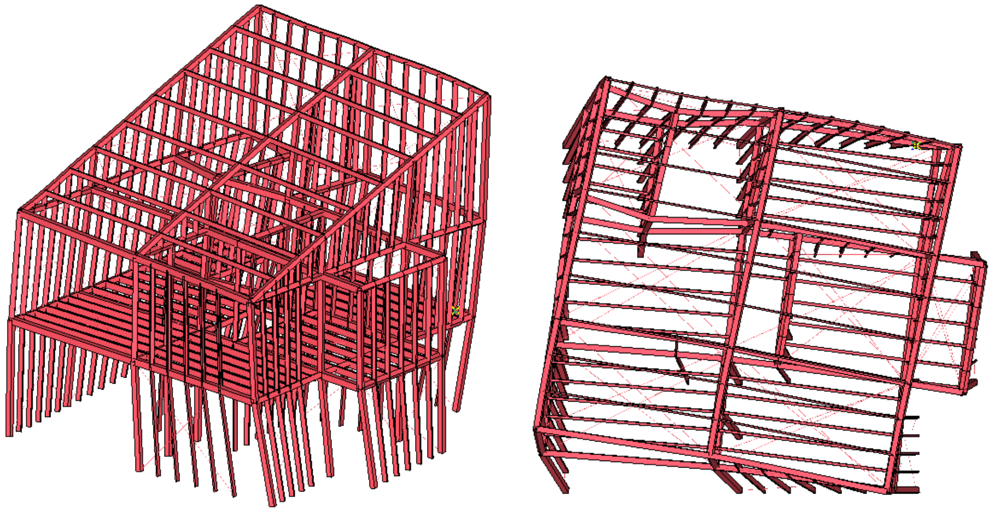


Fig.6.63 - The first 3 mode shapes in the second stage (FE modelling): (a) first mode, (b) second mode, (c) third mode.

The mode shapes described in Table 6.4 are prone to torsion because the centre of rigidity is shifted towards the sheathed walls. The shapes for the second stage are presented in Figure 6.63.

Table 6.4. Dynamic properties obtained by FE modelling.

Stage	T_1(s)	Shape	T_2(s)	Shape	T_3(s)	Shape
1	0.44	Transversal	0.39	Torsional	0.35	Longitudinal
2	0.19	Longitudinal	0.18	Transversal	0.13	Torsional
3*	0.33	Longitudinal	0.31	Transversal	0.23	Torsional

* Note: Only the masses were changed from case 2, stiffness was not affected.

During the *in situ* measurements the working activities at the building site have been stopped, only the ambient vibrations being transmitted to the structure. For each of the three stages of construction, 10 different measurement schemes with 10 velocity sensors were used and for each scheme, two vibration recordings of 2 minutes duration were done with a sampling frequency of 100 Hz. Because of measuring only the response to ambient vibrations (as excitation of the structure) not even the friction forces in the connections have been exceeded.

Based on the analysis of recorded vibrations, the building's modal frequencies (periods) have been estimated using two identification techniques: (i) analysis of the Fourier spectra and (ii) spectral and correlation analysis. For the estimation of the modal frequencies and corresponding damping ratios, the Eigen-system Realization Algorithm (ERA) has been used, which also validated the modal periods obtained by the above mentioned techniques.

The first set of measurements has been done in August 2004. The stage of the construction was that the skeleton of the building was almost entirely completed, as shown in Figure 6.64. The corrugated sheet of the slab was in its final position and fastened above by the OSB panels. However, the roof of the structure was not finished (see Figure 6.64b), not even the purlins for the roof being in place.

Practically, a flexible diaphragm was provided at the level of the first slab but not at the level of the roof.


(a)


(b)

Fig. 6.64 -Construction Stage 1 and sensor location on the skeleton of the structure.

The second set of measurements was done in October 2004 and consisted of the same 10 schemes with 10 sensors. At that time the building skeleton was finished and most of the structural OSB panels were fixed (see Figure 6.65). Some OSB panels were still missing in the attic area. The structural part of the roof has also been finished with the outer corrugated sheath being in place. No work on the finishing (i.e. external thermal insulations, inner or outer wall finishes, slab finishing) has been undertaken at this stage.


Fig. 6.65 - Construction Stage 2 and sensor locations.

The third set of measurements was performed in April 2005, after the completion of the building, before the moving in of the occupants. Therefore, all finishing has been completed but furniture has not been installed. This can be considered the final stage of construction without live load.

Based on this measurements, the period of vibration T_i, the damping ratio, ξ_i and mode shape of the structure have been determined. The results are presented in Table 6.5.

Table 6.5. Modal parameters based on the analysis of ambient vibrations (in different stages).

Stage	Mode 1			Mode 2			Mode 3		
	T_1(s)	ξ_1(%)	Shape	T_2(s)	ξ_2(%)	Shape	T_3(s)	ξ_3(%)	Shape
1	0.546	1.18	Longitudinal	0.437	1.05	Transversal	0.456	1.30	Torsional
2	0.103	3.43	Transversal	0.096	3.72	Longitudinal	-	-	-
3	0.101	4.11	Transversal	0.096	3.80	Longitudinal	0.072	4.12	Torsional

Note: Only the masses were changed from case 2, stiffness was not affected.

The measured results are better that those obtained by calculation, which means that the design procedure is safe enough. It has to be emphasized that the mounting of the stiffening OSB panels not only increased the rigidity of the structure considerably, but the direction of the weakest response has been also changed. In the first stage of construction, the first mode shape was longitudinal (see Table 6.5) with the period $T_{1,St1}$ = 0.54s, while in the second stage it has become $T_{1,St2}$ = 0.10s. It is interesting to observe that at this construction stage, the damping ratio has also increased considerably. At the finished stage, no important change of the vibration properties can be observed. This means that the supplementary mass introduced with the finishing is counterbalanced by the stiffness increase generated by these finishing elements. When live load is added (i.e. furniture etc.) the period of vibration will slightly increase. Most probably T_1 = 0.15 - 0.2s will be reached in use. Another conclusion is that the damping ratio ξ=0.05 is reasonable estimate (even if slightly un-conservative) for light-gauge steel houses.

Masonry structure

The masonry structure has been designed following the above-described architectural plans, considering the same location of the building and the same imposed and climatic loadings. Both buildings (TWCF and masonry) were designed in such a way to achieve similar indoor environment.

For the design of the structure the following input data was considered:

- number of storeys: 2;
- structural system: confined masonry structural walls, made of hollow bricks;
- reinforced concrete slab acting as a rigid diaphragm;
- importance class (according to P100/2006): class III, normal importance (γ_1 = 1.0);
- behaviour factor: q = 2.00;
- characteristics of the seismic action for Ploiesti: a_g = 0,28g ; T_c = 1,0 sec.

According to the design by the Romanian codes CR6-2006 and P100/2006, but also from constructive considerations, the following structural elements resulted:

- concrete stanchions having cross-section of 25×25 cm, reinforced with four bars having the diameter of 12 mm and stirrups of 6 mm diameter at 15 cm. They were disposed according to the following rules: (i) free edges of each structural wall element; (ii) each intersection of walls; (iii) within the walls at a maximum distance of 5 m; (iv) at both sides of any wall opening with an area of more than 1.5 m^2;

- horizontal confining elements placed in the plane of the wall at every floor level (elevations of 3.00 and 6.00m), realized as concrete beams having cross-section of 25×25 cm, reinforced with four bars having the diameter of 12 mm and stirrups of 8 mm diameter at 15 cm;
- floors: designed as reinforced concrete slabs having the maximum span of 3.1 m reinforced with steel wire meshes;
- for all the concrete elements, the class used was C16/20;
- bricks: mark 100 laid with M5 mortar.

Evaluation of Environmental impact

Scope and definition

The scope of the study was the integration of environmental impact into design of buildings, by means of a case-study. The example compares the environmental impact for a single-family house, designed in two different situations: the existing thin-walled cold-formed house and the same house designed in masonry solution – the so-called traditional house. The impact analyses were performed at different levels: (i) construction, (ii) construction and end-of-life, (iii) life cycle including maintenance and, (iv) the life cycle including maintenance and consumable goods.

The comparative life-cycle analysis was performed using the SimaPro software (SimaPro 7, 2008), a general and comprehensive tool, widely used in environmental design and LCA, which uses the Ecoinvent database (Ecoinvent Centre, 2000). In the analyses were included the material production, construction, end-of life for these materials as well as a maintenance scenario for a life-time period of the house of 50 years.

For LCA calculation of the buildings, the input materials have been considered according to the constructive elements: (1) exterior walls; (2) interior walls; (3) flooring system; (4) roof system; (5) foundation-infrastructure. Figure 15 presents the layers used for the distinct components of the house: exterior walls, interior walls, first floor, roof and foundations (including the concrete ground floor).

It should be underlined the fact that the above values contain generic weights as the materials are gathered all-together. *As an example in case of external walls of the traditional house the concrete resulted form the stanchions, although they are present only at each 2.5m and at corners.*

Table 6 gives the total surfaces for the constructive elements, computed by excluding all the openings (doors, windows, technological or staircase opening etc.).

Boundary conditions

In order to set the input elements (inventory analysis), both for simplifying the model and analysis time-saving, the inventory analysis has been done according to system boundary conditions. According to this, several aspects were considered:

- all identical components and materials which are identical as dimensions and weights for both design situations were left out of comparison. They practically bring the same input and output in analysis (for example wall painting or the floor finishing). Including here are the doors/windows and electrical or heating systems;
- the transportation was not taken into account, although the values (especially the weights) are much smaller in case of steel cold-formed house.

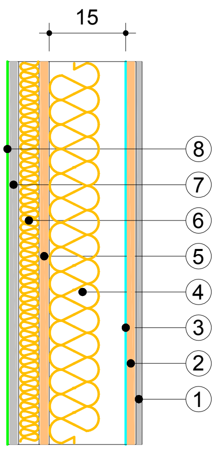
However, these may be introduced at any time in comparison if site is set and materials providers are known;

- the domestic use (water/gas/electricity use) of the two buildings is considered to be similar, as the buildings were designed in such a way to achieve similar indoor environment;
- the energy used for construction purposes (such as cranes and other technological machinery) were not integrated in comparison.

It is to be noticed that due to the lack of information for the Romanian processes and materials, the mean European values were used for the inventory instead.

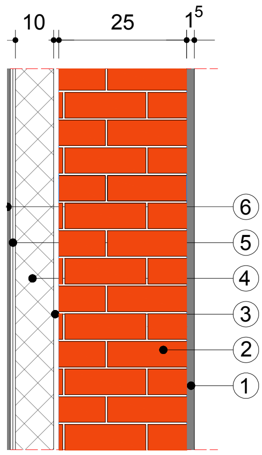
TWCF house

Exterior walls



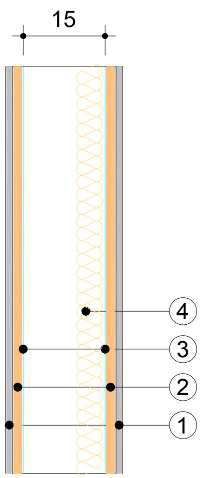
1. Gypsum plaster board 12.5cm
2. Vapour barrier (foil) 2mm
3. Internal oriented strand board (OSB) 12mm
4. TWCF profile / Mineral wool 100mm
5. External oriented strand board (OSB) 12mm
6. Thermoinsulation (polystyrene extruded) 20mm
7. Polyester wire lattice (glass fibre)
8. Exterior plastering (Silicone Baumit) 1.5cm

Traditional (masonry) house

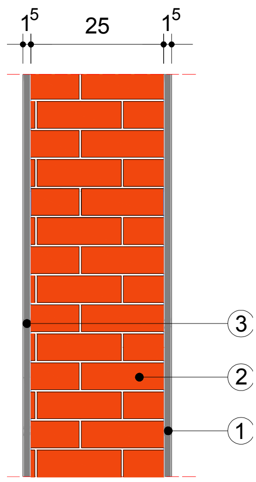


1. Interior plastering (cement mortar) 1.5cm
2. Masonry (bricks) 25cm
3. Adhesive
4. Thermo-insulation (polystyrene extruded) 100mm
5. Polyester wire lattice (glass fibre)
6. Exterior plastering (Silicone Baumit) 1.5cm

Interior walls



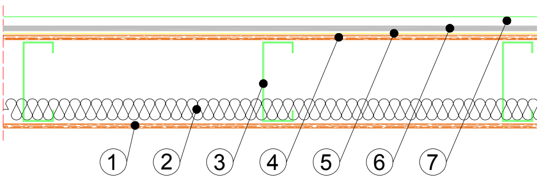
1. Internal and external gypsum plaster board, 12.5cm
2. External and internal oriented strand board, 12mm
3. Vapour barrier (foil), 2mm
4. TWCF profile / Mineral wool, 50mm



1. Interior plastering (cement mortar) 1.5cm
2. Masonry (bricks) 25cm
3. Interior plastering (cement mortar) 1.5cm

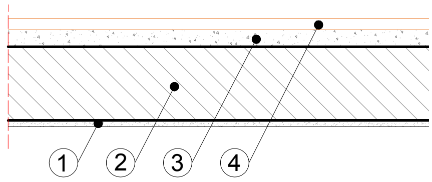
Fig.6.66 - Layers used for structural components.

Floors



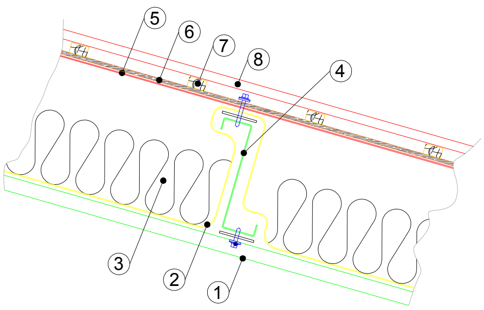
1. Interior gypsum plaster board 12.5cm
2. Thermoinsulation, mineral wool 50mm
3. TWCF profile
4. Oriented strand board (OSB) 15mm
5. Phonoinsulation foil 3mm
6. Oriented strand board (OSB) 12mm
7. Finishing

1. Interior plastering (cement mortar) 0.8cm
2. Concrete slab (concrete) 13cm
3. Concrete flooring (cement mortar) 3cm

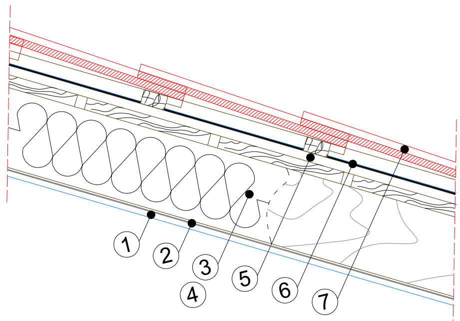


TWCF house

Traditional (masonry) house

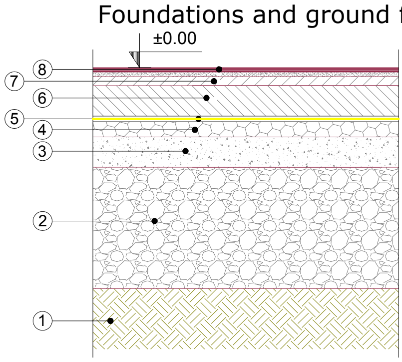


1. Inferior gypsum plaster board 12.5cm
2. Vapour barrier (foil) 2mm, anticondense barrier 2mm
3. Mineral wool 180mm
4. TWCF profile
5. Aluminium antireflex foil 3mm
6. Oriented strand board (OSB) 15mm
7. Timber framing (sawn timber)
8. Steel tiled sheet (coated steel)



1. Inferior gypsum plaster board 12.5cm
2. Vapour barrier (foil) 2mm, anticondens barrier 2mm
3. Mineral wool 180mm
4. Timber rafter
5. 6. Timber framing (sawn timber)
7. Ceramic tiles

Foundations and ground floors



1. Foundation soil
2. Compacted soil 40cm
3. Ballast 10cm
2. Thermo-insulation (polystyrene extruded) 5cm
5. Vapour barrier (foil) 2mm
6. Concrete slab 10cm
7. Concrete flooring (cement mortar) 3cm
8. Finishing

Fig.6.66 - (continued). Layers used for structural components.

Table 6.6. Calculated quantities of materials for construction stage.

Constructive element	*Constitutive materials*	*Use for traditional house*	*Constitutive materials*	*Use for TWCF house*
Exterior walls	Interior plastering (cement mortar)	1.5cm (21kg)	Gypsum plaster board	12.5cm (9.15kg)
	Masonry (bricks)	25cm (207.5kg)	Vapour barrier (foil)	2mm (0.1kg)
	Cement mortar	69.19kg	Mineral wool 100mm	4.5kg
	Thermoinsulation (polystyrene extruded)	100mm (3.5kg)	Internal oriented strand board (OSB)	12mm (7.7kg)
	Polyester wire lattice (glass fibre)	$1m^2$ (0.16kg)	External oriented strand board (OSB)	12mm (7.7kg)
	Exterior plastering (Silicone Baumit)	1.5cm (4.2kg)	Thermoinsulation (polystyrene extruded)	20mm (0.7kg)
	Concrete (stanchions, lintels)	66.54kg	Polyester wire lattice (glass fibre)	$1m^2$ (0.16kg)
	Reinforcing	8.14kg	Exterior plastering (Silicone Baumit)	1.5cm (4.2kg)
			Steel cold-formed profile	16.32kg
Interior walls	Masonry (bricks)	25cm (207.5kg)	Internal and external gypsum plaster board	12.5cm x 2 (18.3kg)
	Interior plastering (cement mortar)	1.5cmx2 (42kg)	Vapour barrier (foil)	2mmx2 (0.20kg)
	Cement mortar	69.19kg	Mineral wool	50mm (2.25kg)
	Concrete (stanchions, lintels)	66.54kg	External and internal oriented strand board	12mm x2 (15.36kg)
	Reinforcing	8.14kg	Steel cold-formed profile	18.33 kg
Floor	Concrete flooring (cement mortar)	3cm (66kg)	Oriented strand board (OSB)	12mm (7.68kg)
	Concrete slab (concrete)	$1m^2$ (312kg)	Phonoinsulation foil 3mm	0.1kg
	Reinforcement (steel)	16.8kg	Thermoinsulation Mineral wool	50mm (2.25kg)
	Interior plastering (cement mortar)	0.8cm (11.2kg)	Inferior gypsum plaster board	12.5cm (9.15kg)
			Oriented strand board (OSB)	15mm (9.6kg)
			Steel cold-formed profile	13.61kg
Roof system	Timber framing (sawn timber)	32.7kg	Steel tiled sheet (coated steel)	5kg
	Ceramic tiles	43kg	Steel cold-formed profile	19.09kg
	Mineral wool	180mm (8.1kg)	Timber framing (sawn timber)	5.16kg
	Vapour barrier (foil)	2mm (0.1kg)	Anticondens barrier	2mm (0.135kg)
	Anticondens barrier	2mm (0.135kg)	Oriented strand board (OSB)	15mm (9.6kg)
	Inferior gypsum plaster board	12.5cm (9.15kg)	Mineral wool	180mm (8.1kg)
			Aluminium antireflex foil	3mm (0.1kg)
			Vapour barrier (foil)	2mm (0.1kg)
			Inferior gypsum plaster board	12.5cm (9.15kg)
Foundatio	Ballast – compacted	10cm	Ballast – compacted	10cm

n/ Infrastructure	Concrete Reinforcement Thermoinsulation (polystyrene extruded)	(540kg) 1752kg 19.12kg 50mm (1.75kg)	Concrete Reinforcement Thermoinsulation (polystyrene extruded)	(320kg) 1078kg 13kg 50mm (1.75kg)

Table 6.7 Computed surfaces for different constructive elements (sqm).

Constructive element	*Traditional house*	*Metallic house*
Exterior walls	216.25	215.1
Interior walls	134.27	126.11
Floors	86.13	80.6
Roof system	100.11	92.54
Foundation	95.36	91.28

Environmental Impact for the Construction Stage

In order to have an easier input of construction materials in LCA tool used (SimaPro 7), there have been computed average values for the weight of materials. These have been estimated for each type of constructive element as follows: the total weight of materials (resulted from the material lists) was divided to the total area of constructive element (in sqm). In this way, the final result represents an aggregate average per square meter of constructive element. This represents in fact the inventory used for SimaPro.

Figure 6.67 and Figure 6.68 present the contribution flow of processes for the construction stage to the environmental impact in the form of process trees for TWCF and masonry structural systems respectively.

Figures 6.69-6.71 present the environmental impact by considering the above input data for construction phase but disregarding the common materials and processes according to the boundaries described in the previous paragraph. All the results are given in "Eco-indicator points" (Pt) (Eco-indicator'99, 2000), which express the total environmental load of a product or process, based on data from a life-cycle assessment, in order to have unitary and comparable outcomes. The method used for impact analysis is Eco-indicator'99.

Figure 6.69 presents the impact for the traditional house for the construction process ranked per constructive elements. The major impact corresponds to exterior walls and foundations. Both constructive elements are high consumers of resources but also have a great impact of human health (each with more than 900 points). However, not the same observations could be said about roofing system, for which the major environmental impact is on eco-system quality, mainly due to high quantity of wood.

Analyzing the TWCF house in the same manner, the results ranked per constructive elements show that also the same constructive elements (external walls and the foundations) have the lead on the environmental impact.

In a direct comparative impact analysis, for traditional house, higher impact values for most of the impact indicators (categories) result, as could be seen in Figure 6.70. One could realize that for both structures the major impact is for fossil fuels, as these resources are used for the fabrication of building materials at all levels. Also, important values of impact are recorded for inorganic respiratory emissions, climate change substances and land use. Although in the case of carcinogens and ecotoxicity, the impacts have comparable values, large differences could be noticed in case of land use (2.5 times larger the environmental impact of steel house), fossil fuels, respiratory inorganic substances and climate change (at least 2 times greater for traditional house).

The results, on impact (or damage) categories, are aggregated into a single score (inner figure), leading to an overall score of 1626 points for the metallic house, less than half of the global score of the traditional house (3409 points).

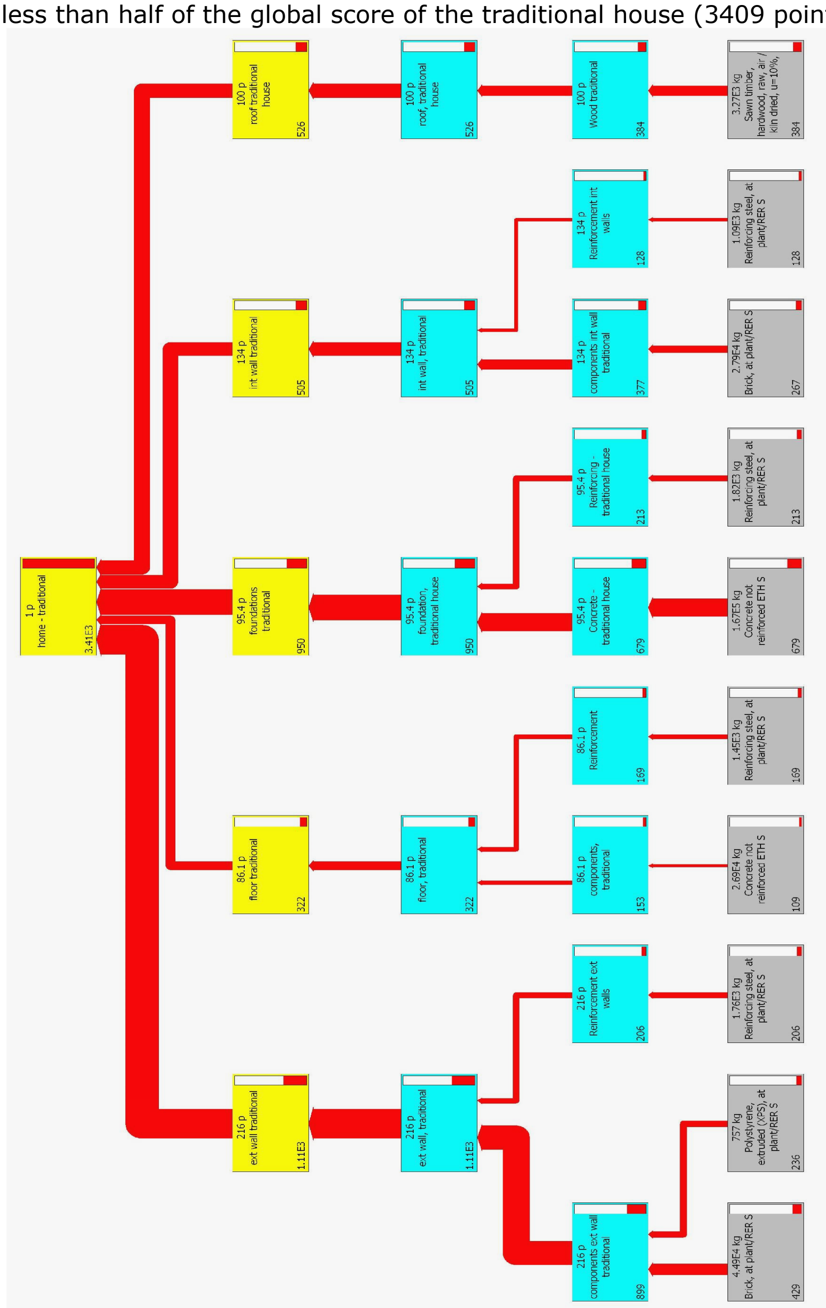


Fig. 6.67 - Process tree for construction stage of the traditional house.

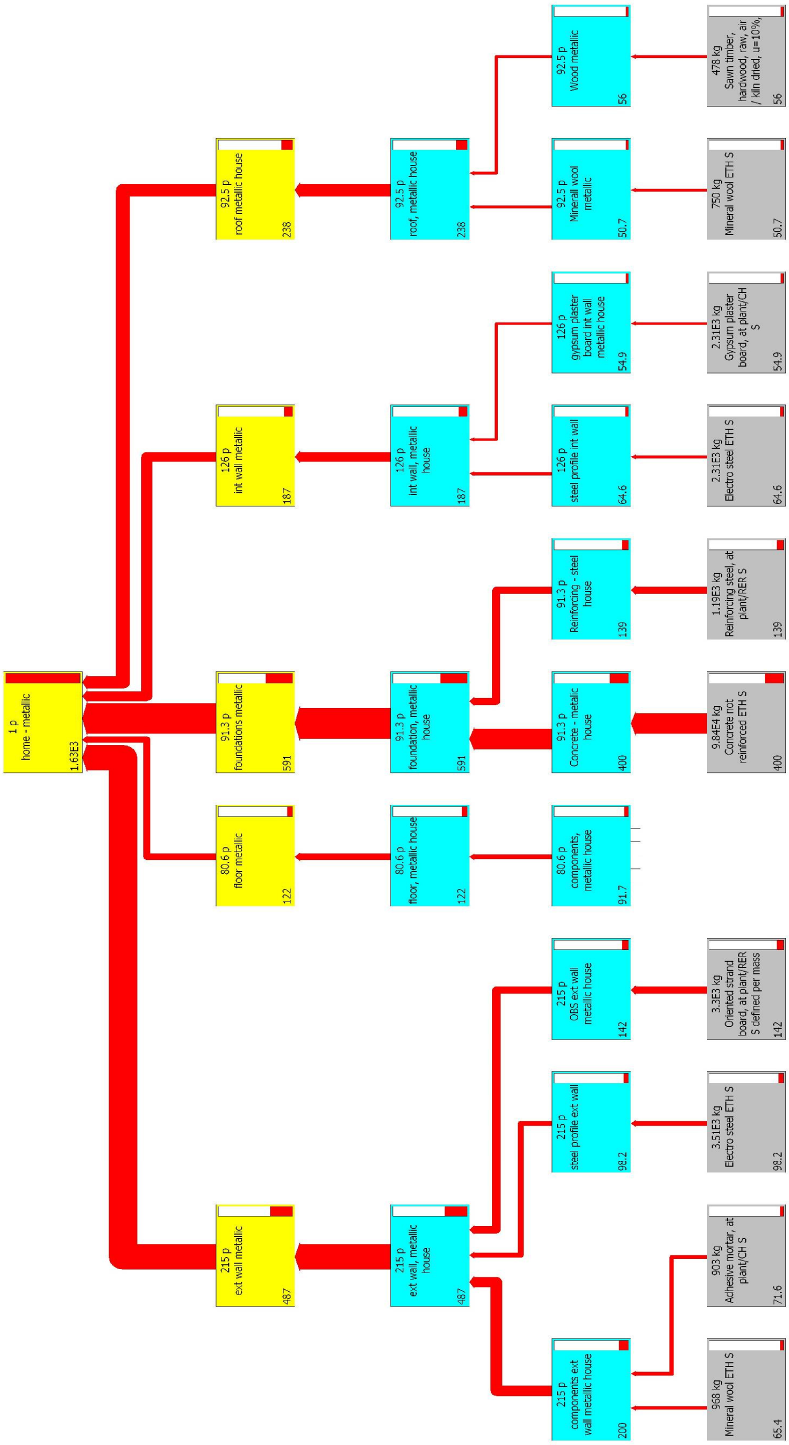


Fig. 6.68 - Process tree for construction stage of the metallic house.

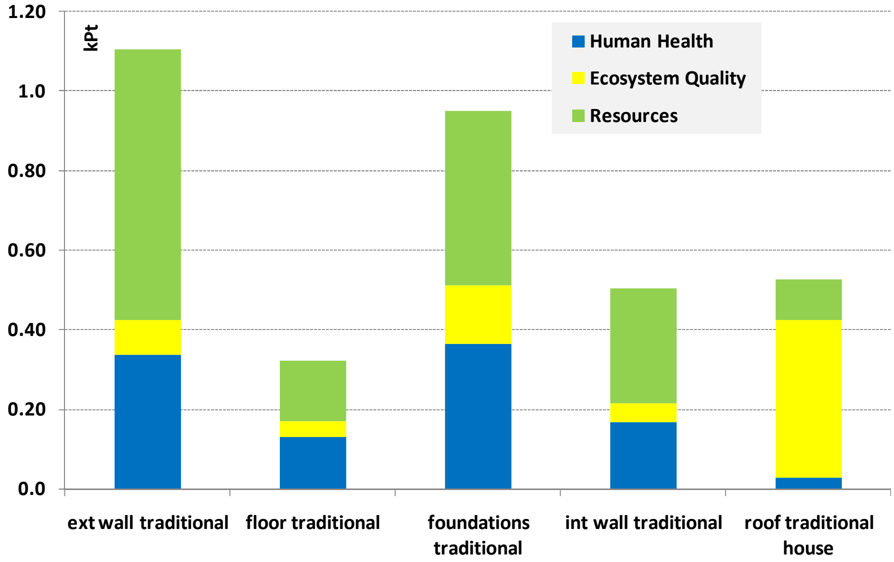


Fig. 6.69 - Environmental impact per constructive element for traditional house – construction phase.

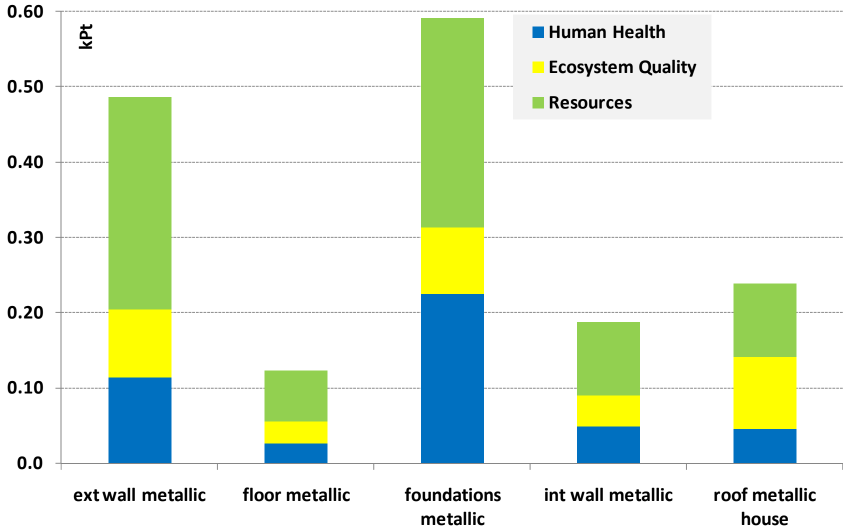


Fig. 6.70 - Environmental impact per constructive element for metallic house – construction phase.

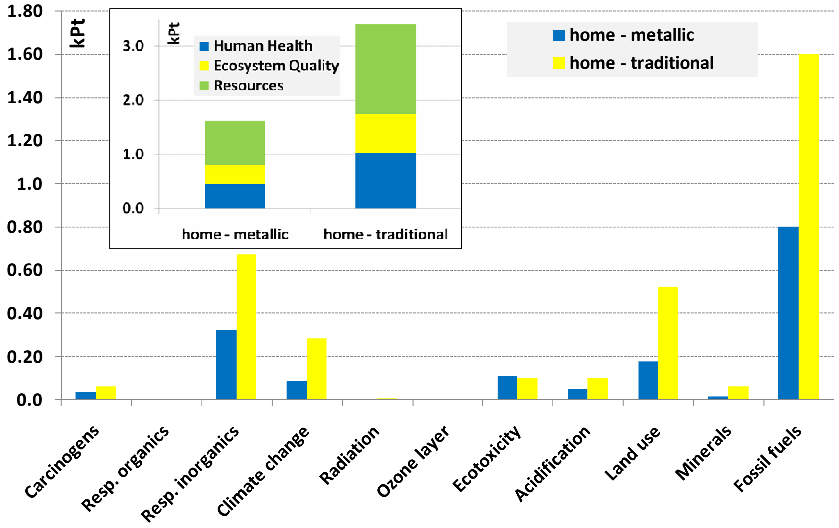


Fig. 6.71 - Comparison on environmental impact for metallic and traditional house (weighting).

Environmental Impact Considering the Construction Stage and End-of-Life (Recycle, Reuse and Disposal)

It is certain that the building process is not complete without an end-of-life for the materials if considering the life-cycle approach. Normally, the final destination of waste building materials represents a problem in every country, but may differ even within a country, from zone to zone. There are materials that could be reused in the form they are for the same purpose (ballast for example), others that could be reused for other less important purposes (low-cycling - e.g. crushed concrete as street bed-layer), and others that need waste treatment (incineration) or used simply as land-fill.

For the purpose of our study, the end-of-life of integrated materials was thought according to present conditions in Romania for recycling, reuse and disposal. The end-of life scenarios for the main building materials considered in the analysis were based on inquiry of site engineers about the present conditions in Romania, which are summarized in Table 6.8.

Table 6.8. End-of life for building materials.

Building material	*Reuse [%]*	*Recycling [%]*	*Burn [%]*	*Landfill [%]*
Steel – steel profiles, steel tiled sheets	---	100	---	---
Steel – reinforcement	---	80	---	20
Bricks, ceramic tiles	---	---	---	100
Wood	35	---	65	---
OSB	50	---	50	---
Gypsum plaster boards	30	---	---	70
Ballast	70	---	---	30
Concrete, mortar	---	---	---	100
Other inert materials	---	---	---	100
Other combustible materials	---	---	100	---

In these conditions, ranked in a single score (see Figure 6.72) it results that in the life-cycle comparison for the construction and disposal scenarios, the gap between the two situations is greater than in the case of construction process only. As could be noticed, for both structural systems, the end-of-life scenario brings a negative impact (global scores being now 1779 points for TWCF and 3986 points for masonry one respectively) although some benefits are obtained by the reuse of certain materials (wood, ballast, OSB and gypsum plaster boards).

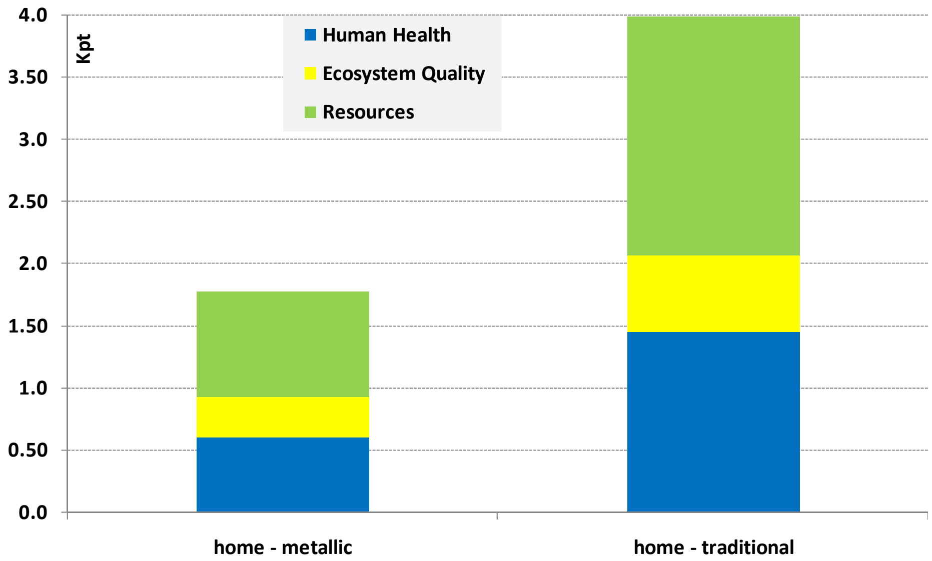


Fig. 6.72 - Comparison on environmental impact for metallic and traditional house (global score) - construction phase and end-of life.

Integration of the Maintenance of Buildings

Regardless the chosen constructive system, a building needs maintenance works during its life-cycle. These works could be of different types and, function of this type, could be more or less expensive and they represent a very important part of the building life-cycle.

The integration of maintenance works for a structure is difficult to make, because the predictions that could be made in advance may not correspond to reality. However, in order to complete the life-cycle of buildings under consideration, the following prediction (pre-planned maintenance) was made for a house, thought for a standard life-time of 50 years:

i) In case of the traditional house:

- nine internal decorations (once at 5 years);
- three external decorations (once at 12.5 years);
- three changes for bathroom/kitchen sanitary: sandstone, sanitary furniture, internal plaster-board etc. (once at 12.5 years);
- one change of the electric and heating system (once at 25 years);
- one change of the roofing system (wood and cover) (once at 25 years);
- one change of the exterior thermo-system (once at 25 years).

ii) In case of the metallic house:

- nine internal decorations (once at 5 years);
- three external decorations (once at 12.5 years);

- three changes for bathroom/kitchen sanitary: sandstone, sanitary furniture and adjacent internal plaster-board (once at 12.5 years);
- one change of the electric and heating system (once at 25 years);
- one change of the steel tiled sheeting (once at 25 years);
- one change of the thermo-system for interior walls, including OSB and plaster-board panels, on one face of the wall (once at 25 years);
- one change of the thermo-system and external OSB panels for external walls (once at 25 years).

Important to notice is the fact that, in case of steel structure, only the steel skeleton and some OSB and plaster-board panels remain unchanged, while all other elements are changed once in 50 years. Of course this is the worst scenario and, different scenarios can be proposed too. For traditional house, the maintenance reduces here at the level of plastering for walls, thermo-system and part of the roof-wood supporting. For both cases, no maintenance was considered for infrastructure.

In addition, for the life-cycle assessment, the same conditions for disposal at the end-of-life have been considered in accordance to the previous explanations.

Figure 6.73 presents the impact deduced only for maintenance process. As the quantities introduced for analyses are smaller than that from the building process, the global scores are also smaller. In terms of impact categories, the same indicators (fossil fuels, respiratory inorganic substances and land use) integrate more than 85% of the global scores. In case of maintenance for steel house, the eco-toxicity is also a mentionable category to global score.

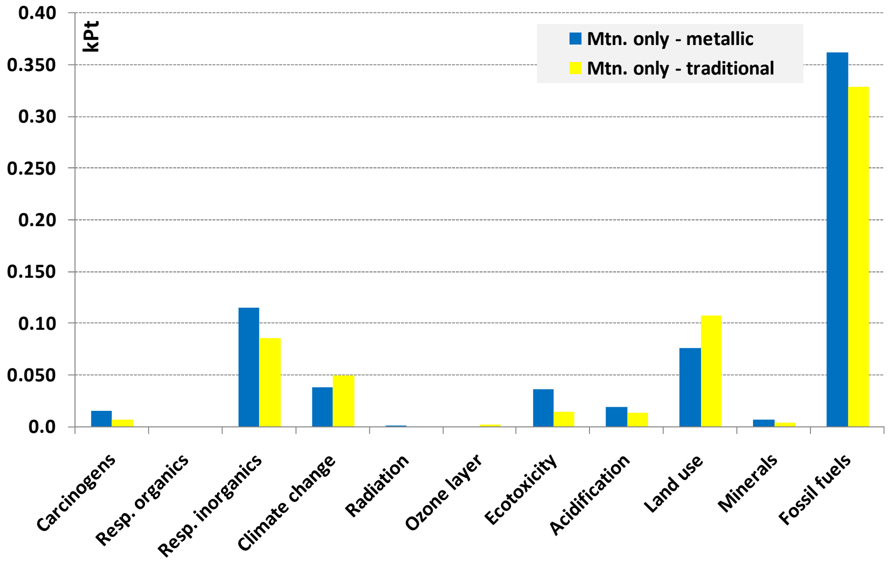


Fig. 6.73 - Comparison on environmental impact for metallic and classic house - maintenance only.

All the values resulted only from maintenance and cumulated in a single score (see Figure 6.74) will conduct to about 670 eco-points in the case of TWCF house and respectively 615 eco-points for the traditional house. This is somehow in contradiction with the values derived for the construction process, where the ratio is reversed in the favour of the TWCF house. The explanation for this derives from the facts that for the steel house one side of walls, floor and roof layers are replaced while in the case of traditional house, all the brick, concrete, wall plastering and main wood frame remain in the original form.

Figure 6.75 and Figure 6.76 present the above – described stages from the life-cycle of buildings as a direct sum of:

- the construction stage;
- the disposal at the end-of-life for different materials;
- the maintenance of the building for a life-time period of 50 years.

As a general trend, the following impact categories are most affected:

(i) *fossil fuels, respiratory inorganic substances and climate change*: mainly due to the manufacturing processes which require large quantities of energy and further on affect directly the fossil fuel reserves. These processes contribute in high extent to the emissions of inorganic substances and climate change gasses;

(ii*) land use*: due to damages to land use (wood exploitation, ballast pits etc.).

As a general rule, the differences obtained in the life-cycle analysis including maintenance follow the trend observed in case of building process itself, namely almost all the environmental impact categories are greater for the traditional home.

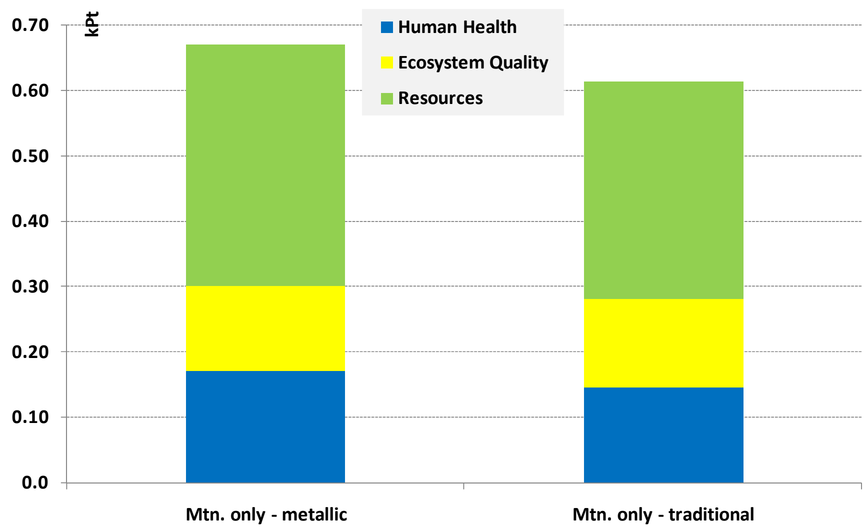


Fig. 6.74 - Comparison on environmental impact for metallic and classic house – maintenance only (global score).

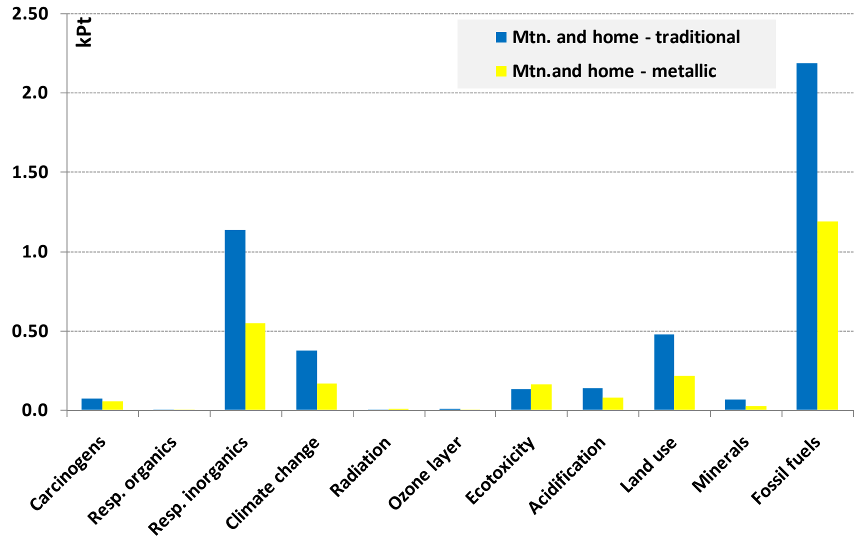


Fig. 6.75 - Life-cycle comparison on environmental impact for metallic and traditional house (weighting) for construction, including maintenance and end-of-life.

In a single score analysis (see Figure 6.76), and taking into account the boundary conditions as explained before, the metallic house (2450 eco-points) presents an important advantage in front of traditional one (4600 eco-points). Of course, many parameters (such as national or regional peculiarities, climatic zones or distance from the material distributors) may affect these results.

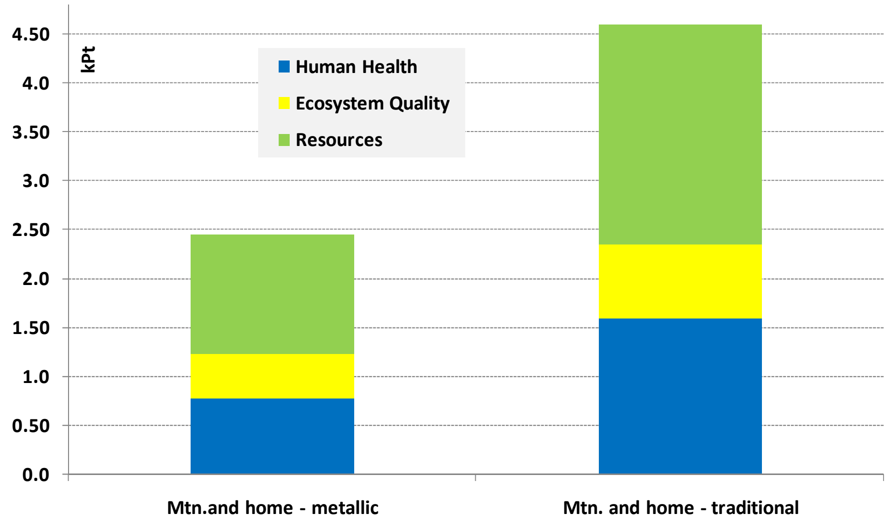


Fig. 6.76 - Life-cycle comparison on environmental impact for metallic and traditional house (weighting) for construction, including maintenance and end-of-life.

LIFE-CYCLE INCLUDING CONSUMABLE GOODS

General considerations

In order to complete the life-cycle assessment of the house, the consumable goods (electricity, water etc.) should be estimated. In our case, the estimation for these goods was made for a standard life-time period of 50 years.

The energy considered in this study is used for heating, cooling processes, domestic use of electrical devices, lightning and so on. The values taken into consideration in our comparison are based on mean computation for power consumption per capita or per surface, while in the case of heating/cooling there have been considered the particular characteristics of each structural system.

Taking into account that both systems were designed in order to accomplish the same interior thermal and comfort conditions and are conceived for same use in electric power and water, they lead practically to the same need of consumable goods.

Three main components were considered as consumable goods, as follow:

- *water*, used for domestic purposes, as cold and hot. The hot water is prepared at home;
- *electricity*, used for lighting, electrical devices, cooling system;
- *natural gas,* employed in heating the house during cold months and for hot water preparation.

Calculation of consumable goods

Estimation of the annual natural gas requirement

As already mentioned, the natural gas was considered the source used for heating and hot water preparation. For this purpose, first of all, it is necessary an estimation of the quantity of heat required during one year. This was performed according to the Romanian standards SR 1907-1:1997 and SR 1907-2:1997, as function of the interior and exterior temperatures and construction elements.

Practically, for each distinct component delimiting the house rooms (walls – including windows and doors, ceiling and floors), there have been computed the resistance to thermal transfer. Then, as function of outside temperature (monthly mean) and the required inside temperature, the required heat quantity was computed.

The resistance to thermal transfer was computed by the following equation:

$$Q = Q_T[1 + (A_0 + A_c)/100] + Q_i \qquad (6)$$

where:

Q_T represents the thermal flux through the delimiting elements (walls, windows and doors in steady regime);

Q_i is the required heat for warming the air flow, cooled due to doors and windows opening, from exterior to interior temperature;

A_o North-South orientation addition;

A_c addition for cold-surfaces compensation.

The thermal flux through the delimiting elements was computed by:

$$Q_T = A \cdot (m/R) \cdot \Delta t \cdot C_M + Q_p \qquad (7)$$

in which:

A represents the area of the delimiting element;
R is the element resistance to thermal transfer;
C_M is a coefficient given function of the relative mass of the building, taken as 0.94;
m the thermal massivity of material (computed in function of the thermal inertial index);
Δt represents the interior-exterior thermal difference;
Q_p is the heat transmitted through the floor.

For our study, the thermal resistance was computed for each type of delimiting component. Table 6.9 gives, as an example, the way of calculation of the thermal resistance for the external wall of the traditional house. From the wall materials, there have been considered those having an important conductivity (mortar, polystyrene and masonry bricks). The stratification of this wall has been presented previously.

Table 6.9. Computation of thermal resistance (example for an exterior wall).

Exterior wall (25 cm)							
Name	*Thermal conductivity*	*Thermal assimilation*	*Element width*	*Thermal resistance*	*Total thermal resistance*	*Thermal inertial index*	*Thermal massivity*
	l (W/mk)	s (W/m²k)	d (m)	RO (m²k/W)	R=RI+RE+ RO (m²k/W)	D	m
Cement mortar	0.9330	10.08	0.03	0.0323	3.0626	0.3252	
Hollow brick	0.330	7.64	0.25	0.7576	0.0420	5.7879	
Polystyrene	0.044	0.30	0.10	2.2727	0.1250	0.6818	
				3.0626	3.2296	6.7949	1.00
R = 3.2296							

Table 6.9 summarises the thermal resistances of all elements/components, computed as above, function of the system stratification. The thermal insulation resistance of main thermo-resistant elements (external walls and roofing system) shows similar values, fact that allows the assumption of using the same amount of heat for both systems (assumption proved by actual calculation).

Table 6.10. Comparison of thermal resistances per elements for traditional vs. metallic house.

Element name	*Thermal resistance for traditional house (m²k/W)*	*Thermal resistance for metallic house (m²k/W)*
Exterior wall	3.2296	3.1187
Interior wall	0.9461	1.4185
Floor on ground	2.7724	2.7724
Floor over 1st storey	0.6462	1.6911
Floor over 2nd storey	4.5464	4.5464

The heat requirement has been computed taking into account three assumptions: (i) in the houses are living 3 persons; (ii) the external mean temperatures were considered for the city of Ploiesti, location in which the structure was build and (iii) the interior ambient temperature was considered 20°C. On these presumptions, it results a daily requirement for heating. Table 6.11 presents, as an example, the heating requirement for one day in January, for the first floor. The total heat requirements, for both houses, are given in Table 6.12, in watts.

Table 6.11. Heat requirement for first floor in January example of computation.

Wall, floor name	*Orientation*	*Width*	*Height*	*Surface*	*To subtract*	*In calculus*	*R"*	*m*	*Δt*	*Q"*
		[m]	[m]	[m^2]	[m^2]	[m^2]	[m^{2}k/W]		[°C]	[W]
FP1	1	11.05	2.7	29.84	13	16.9	3.2296	1.034	22	164.26
FP2	2	11.05	2.7	29.835	3.51	26.3	3.2296	1.034	22	182.47
LE3	3	9.45	2.7	25.52	9.54	16	3.2296	1.034	22	110.47
LV4	4	9.45	2.7	25.52	6.26	19.3	3.2296	1.034	22	133.19
G+U				32.27	0	32.3	0.667	1.000	22	1,044.86
F				90.46	0	90.5	2.7724	1.069	16	557.94
PP				90.46	0	90.5	0.6462	1.133	0	-
TOTAL										**2,145.21**

Table 6.12. Heat requirement (watts) for one year.

Month	*No. days.*	*Traditional house*		*Metallic House*	
		Heat req./ day	*Heat req./ month*	*Heat req./ day*	*Heat req./ month*
January	31	3,996.501	2,973,396.74	4,070.78	3,028,658.71
February	29	3,434.891	2,390,683.99	3,502.78	2,437,933.13
March	31	2,659.99	1,979,032.77	2,710.63	2,016,708.07
April	30	1,636.914	1,178,577.92	1,670.66	1,202,878.70
October	31	1,636.914	1,217,863.86	1,670.66	1,242,974.66
Nov	30	3,229.963	1,915,193.00	2,710.63	1,951,652.97
Dec	31	3,585.165	2,667,362.80	3,644.35	2,711,392.96
	TOTAL (Q_{inc})		**14,322,111.08**	**TOTAL(Q_{inc})**	**14,592,199.21**

The required energy for heating water was computed in accordance to the following formula:

$$Q_{ac} = m \cdot c_p \cdot \rho \cdot (t_{ac} - t_{ar}) \text{ [kJ]} \quad (8)$$

where:

m is the water flow rate in kg/hour;
c_p the thermal capacity of water;
ρ the water density (1000 kg/m^3);
$t_{a.c.}$-$t_{a.r.}$ the hot (45ºC in mean) and cold (10ºC in mean) water temperature.

The required volume of hot water per day was fixed at 110 l for each inhabitant, leading to a total amount of 330 l/house/day.

Resulted total heat requirement for a house is then given by:

$$Q_{tot} = Q_{ac} + Q_{inc} \tag{9}$$

where:

Q_{inc} is the required energy for heating.

The total heat requirement Q_{inc} computed for the traditional house is 14322 kilowatt and for the metallic house is 14592 kilowatt; the difference being less than 2%, further on, they would be considered as being the same value (14322 kilowatt).

The gas requirement is then computed by:

$$M = Q_{tot} / q_{gas} \tag{10}$$

where, q_{gas} is the thermal power of gas taken as 8.5 mc/kW.

It results the following values (see Table 6.13) for the total requirements of energy and its translation in gas volume burnt in domestic gas heating power station (computed by Eq. 5).

Table 6.13. Annual heat requirement and gas equivalent.

Q_{inc} [kilowatt]	14322
Q_{ac} [kilowatt]	4902
Q_{tot} [kilowatt]	19224
M [m^3]	**2262**

Estimation of the annual domestic electrical power

In order to compute the annual domestic power consumed by the inhabitants, it was considered the following configuration of the electric board:

Table 6.14. Electric board scenario.

No.	Circuit No.	Consumer denomination	P_i kW]	P_f kW]	K_u	cos.	tg.	CHARGE Active P_a [kW]	Reactive Q_{nec} [kVar]	Apparent S [kVA]
1	TD1.1	1st floor lightning	1.00	1.00	0.60	0.80	0.75	0.6	0.19	0.8
2	TD1.2	2nd floor lightning	1.00	1.00	0.60	0.80	0.75	0.6	0.19	0.8
3	TD1.3	Sockets – 1st floor	2.50	2.50	0.60	0.80	0.75	1.5	0.49	1.9
4	TD1.4	Sockets – 2nd floor	2.50	2.50	0.60	0.80	0.75	1.5	0.49	1.9
5	TD1.5	AC Split	3.00	3.00	0.60	0.80	0.75	1.8	0.58	2.3
6	TD1.6	Washing machine	1.50	1.50	0.60	0.80	0.75	0.9	0.29	1.1
TOTAL			**8.50**	**11.50**				**6.9**	**2.2**	**8.6**

Taking into account the temperature fluctuation during the summer months, it was considered a monthly consumption of 200 kWh for summer months respectively 120 kWh for cold months. The difference is due to the use of Air Conditioning Split.

Consequently, the annual electrical power consumption is:

$$W = 6 \times 120 + 6 \times 200 = 1920 kWh \tag{11}$$

resulting for the entire life of house of 50 years, a value of 96000 kWh.

Estimation of the annual water used

Considering the house inhabited in mean by 3 persons, the cold and hot water requirement was considered as 20 m^3 per month (the warming of the hot water was integrated into the annual gas estimation). These values resulted also by considering the national values. The annual water consumption results as:

$C = 12 \times 20 = 240 m^3$ per year (12000 m^3 for the entire life of the house) (12)

Life-cycle analysis including energy scenario

According to the calculation presented in the previous paragraph, the following quantities of consumable goods – computed for a lifetime period of 50 years – have to be introduced supplementary in the LCA analyses (see Table 6.15). No disposal scenario was considered for the consumables.

Table 6.15. Consumable goods used for LCA.

Consumable	*Quantity*
Water [m^3]	12000
Gas [m^3]	113100
Electricity [kWh]	96000

Figure 6.77 presents the impact on environment for these consumable goods. In terms of impact categories, the highest impact is taken by fossil fuels, fact that is normal in regard to the elements considered (gas, electricity and water). The other impact categories are negligible in regard to fossil fuels category. It has to be noted that in the energy scenario was not included any solution of using renewable energy, as these could diminish the fossil fuel requirement.

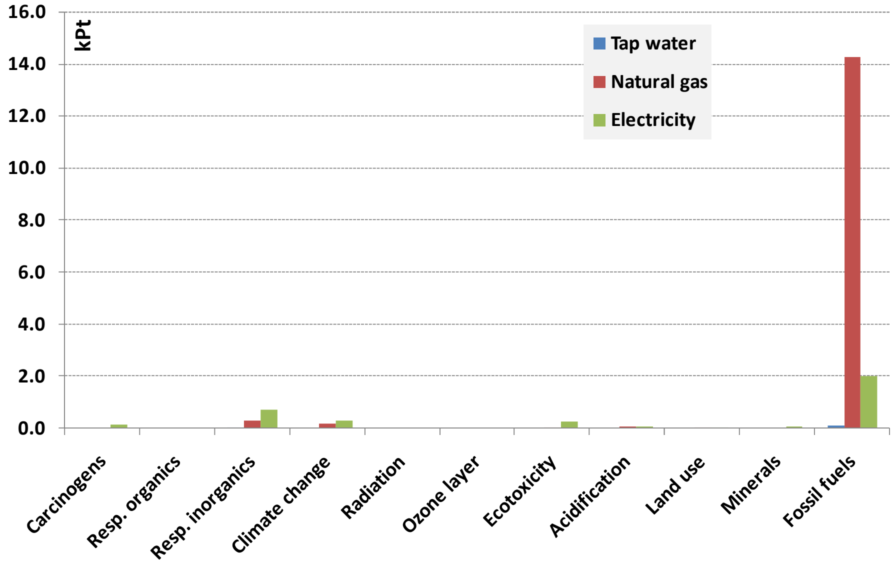


Fig. 6.77 - Environmental impact (weighting) – consumable goods only.

Observing the share of impact categories for different consumables considered: gas, electricity and water, it could be drawn very easily the conclusion that the gas affects largely the fossil fuel category.

Comparing now the environmental impacts produced by consumable goods relative to the building process including maintenance, it could be easily observed that, by far, the consumable goods take the highest impact (more than 7.5 times in case of metallic house and 4 times more in case of traditional house). These results are both considered for the entire life-time period of a house (50 years). It can be seen that the difference arises due to the use of fossil fuels affecting the resources category and not due to human health damage substances or eco-system quality. As a main comment, it should be said that since the energy consumption for heating take the lead in the consumable goods impact and depends on the thermal resistance of envelope elements, these ratios could be diminished by better insulation.

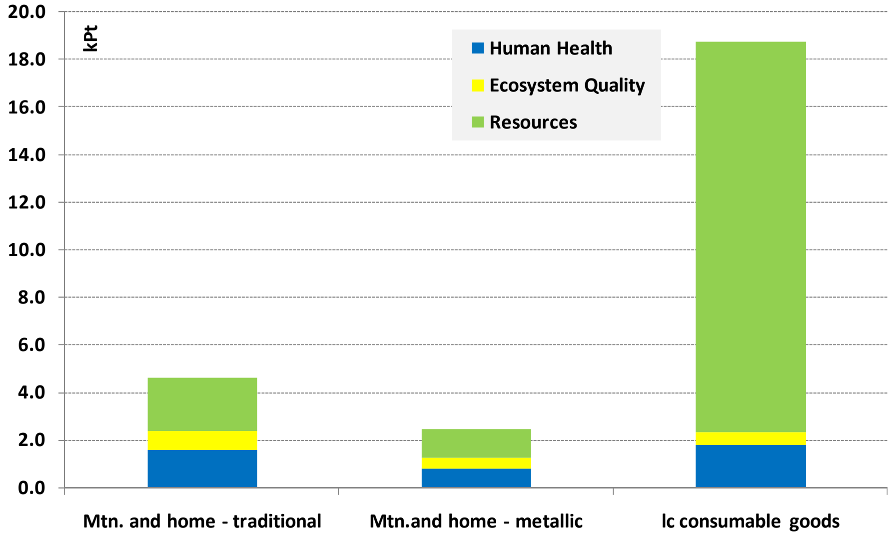


Fig. 6.78 - Single score comparison of environmental impact for building process and consumable goods.

In a direct conclusive comparison, by considering the building process and consumable goods, according to the analysis performed in the conditions described herein, the total global impact score for a life-time period of 50 years is by 10% smaller in case of the metallic structure.

In conclusion it could be stated that a metallic house could represent a good alternative to the usual traditional Romanian house in terms of environmental impact.

CONCLUSIONS

A modern design of buildings should integrate aspects related to their sustainability in addition to the economic, safety and functionality requirements. The study presents the practical aspects related to the environmental impact analysis of an existing dwelling made with light-steel structural elements. In order to have a base of comparison of the investigated solution, a comparison with a traditional solution was done, for this purpose a similar masonry house being designed.

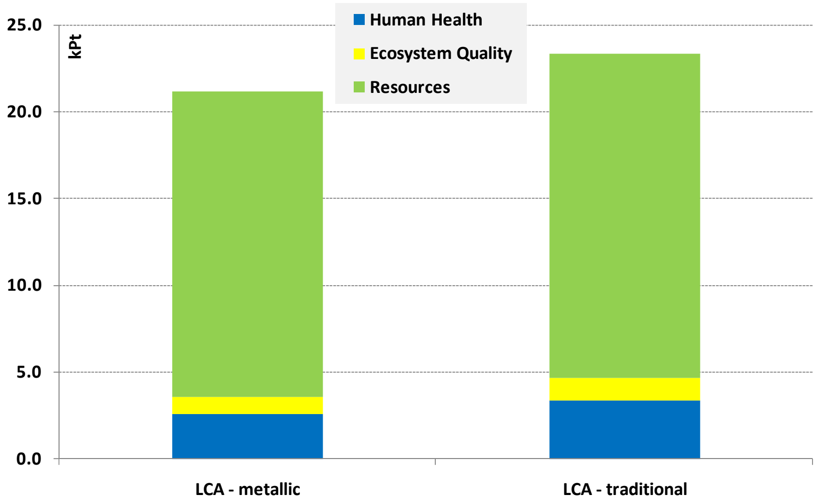


Fig. 6.79 - LCA comparison of environmental impact (single score) for metallic and traditional houses for building process and consumables.

Within the purpose of the study, a series of boundary conditions have been set. In order to have a good overview of the LCIA analyses, the results are presented in different stages:

- by considering the constructions process only;
- construction process integrating the end-of-life scenario;
- construction process, end-of-life and maintenance.

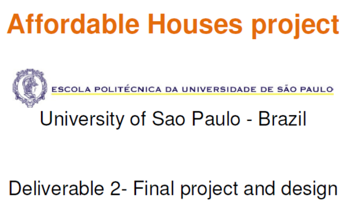
The conclusions of the study can be summarized below:

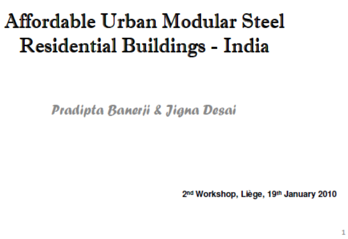
- in all the stages the global and individual main category scoring of steel structure is significantly smaller than that of traditional house;
- a proven advantage of steel housing is represented by steel recyclability which brings positive impact at the end-of-life stage. This is in contrast to the modern (hollow) bricks that cannot be recovered once that they are plastered;
- the maintenance process is however more disadvantageous for steel dwelling, the change of thermal system includes also the change of all the wall layers. This is directly reflected in the environmental impact;
- the results presented show very clear that the major impact on environment is not due to the building itself (including maintenance), but to the energy consumption during its use. Furthermore, impact category that takes the major impact is represented by the use of the fossil fuels;
- as a main conclusion of the study, it could be stated that steel dwellings with cold-formed structural elements represents a good alternative to masonry houses, not only with respect to structural requirements but also in considering the environmental impact assessment.

Nevertheless, the above conclusions are drawn on the limits of the study described. Several other parameters (such as transportation or the operational energy) may change the result ratios in the comparison.

The constructive system used for TWCF steel house, has been proved to be an efficient alternative not only for the building process, but also for the consumable goods used during the life-time.

6.8. Affordable House - Arcelor





PARTICIPANTS TO THE ARCELOR MITTAL „AFFORDABLE HOUSE PROJECT"

When it comes to affordable houses, the basic preoccupation of designers is to find a good relationship between cost and comfort. One supplementary parameter could be the erection time in some cases. That is why architects and engineers try to find solutions that rely on usual building materials but apply innovative systems.

In this context, an innovative structure/envelope solution is proposed by:

– the application of industrial building technologies in dwelling building systems (residential applications) achieving fast erection and fabrication times. The basic assumption is that an affordable house should rely on the standard details and common technologies available to most builders instead of experimenting with new materials with no track record.

– the development of a modular system in such a way that at any time the owner can add a new module, both vertically and/or horizontally, with a high solution diversity for floors and envelope.

– the design – in terms of structural performance – of both the walls and the floors based on stressed skin technology. It is well known that using oriented strand board (OSB) panels for walls and profiled steel sheeting as the floor decking results in very effective shear diaphragms. Provided they are positively attached to the secondary members and main frames by mechanical fasteners or welding, they are extremely reliable and predictable, and may be confidently used as structural components.

– the use of structural systems made from lightweight steel frames, hot-rolled sections or timber framing, which assures the lightness of the house and the proper response to climatic and seismic loading.

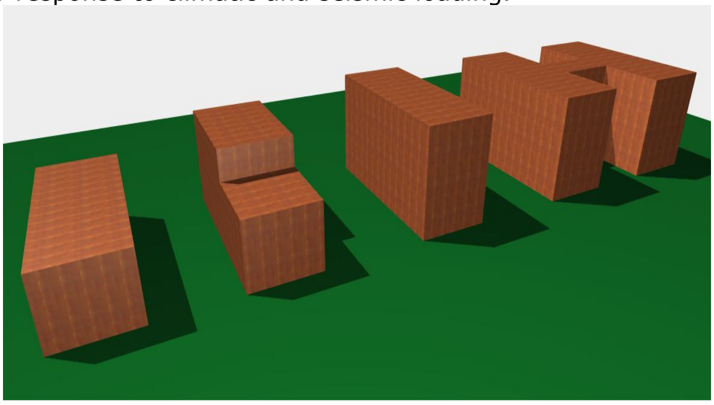


Fig. 6.80 - Modular progression of the typical one level unit

The architectural concept relies on the development of a rectangular footprint of 5.60 × 13.40 m, which gives a first module of 75 m^2 for a one-level unit. The dwelling is a two-storey building, with rooftop terrace, having a gross built area of 150 m^2 and a usable area of 124.41 m^2.

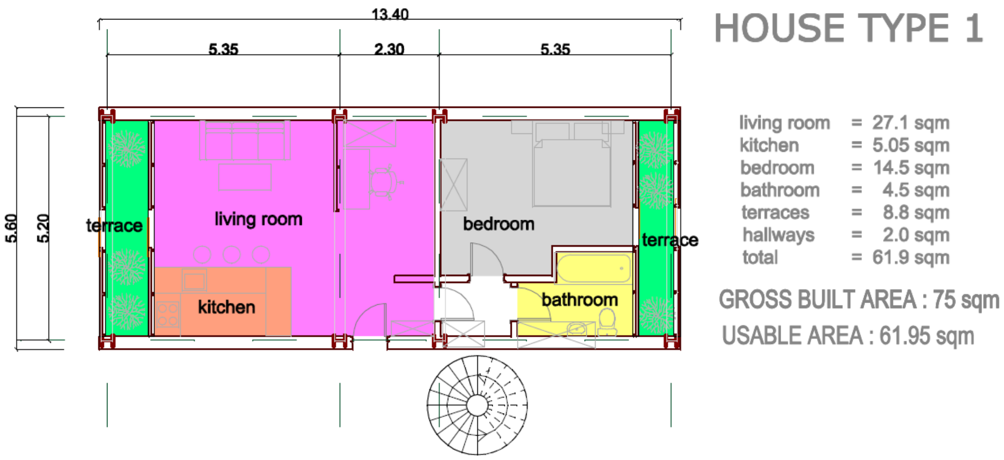


Fig. 6.81 - Affordable House Type 1 - single level unit

Fig. 6.82 - Affordable House Type 1 – 3D view

Further development of the house is possible by adding a new module by horizontal addition, thus extending the living area.

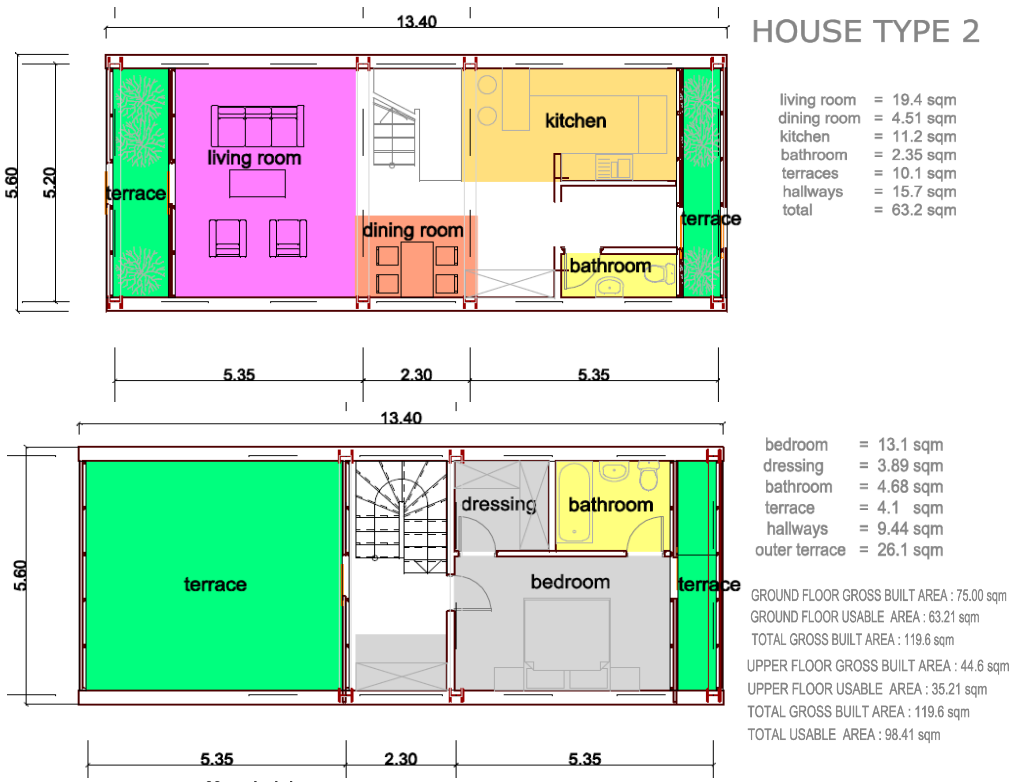


Fig. 6.83 - Affordable House Type 2

Fig. 6.84 - Affordable House Type 2 – 3D view

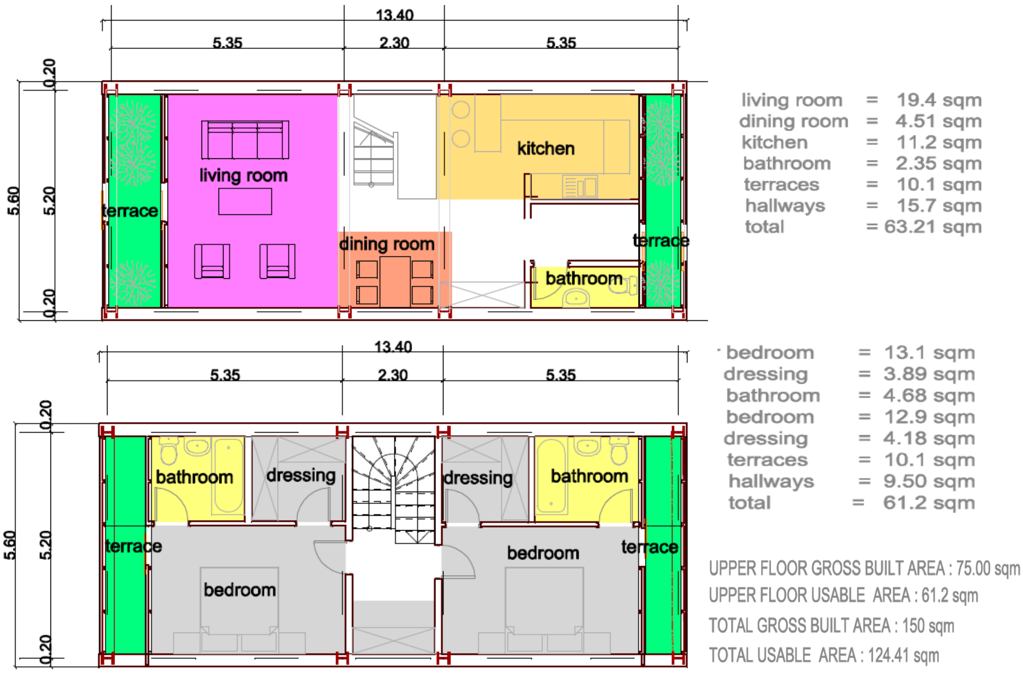


Fig. 6.85 - Affordable House Type 3 - 2 level house

Fig. 6.86 - Affordable House Type 3, 3D view

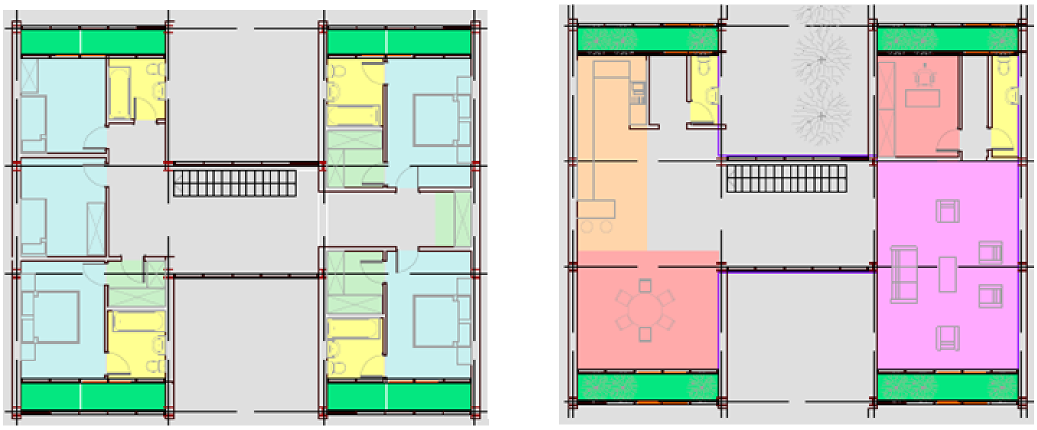


Fig. 6.87 - Affordable House Type 4 – plans

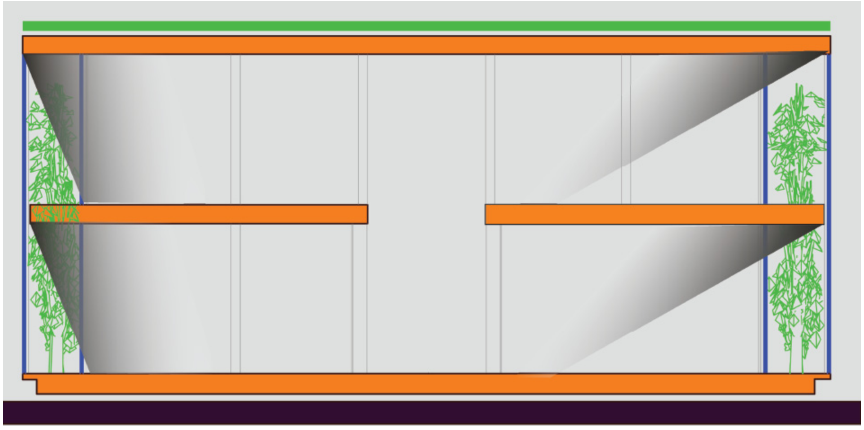
Fig. 6.88 - Affordable House Type 4, 3D view

The proposed construction system consists of:
(1) hot-rolled framed steel structure;
(2) secondary structure – cold-formed steel (or timber) studs;
(3) various envelope systems;
(4) floor structure – lightweight concrete topping on trapezoidal steel deck;
(5) double-glazed loggias with PVC or aluminium frames;
(6) foundations and slab – in situ reinforced concrete;
(7) rooftop terrace or pitched roof.

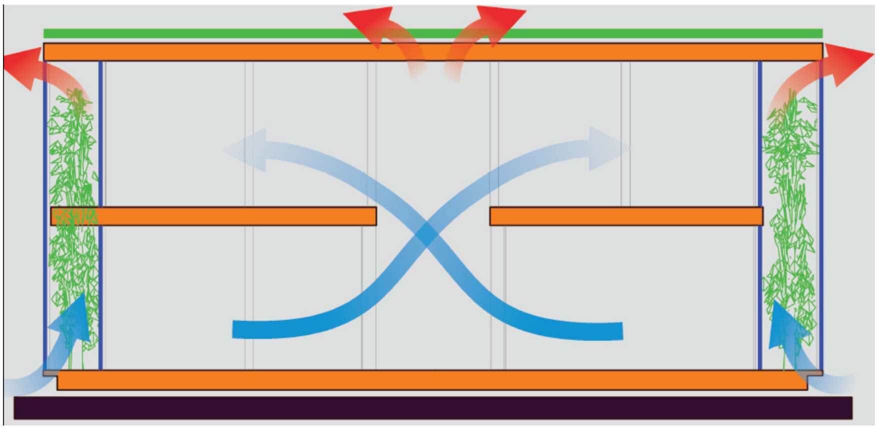
The design solution can be adapted to maximize the steel component or to incorporate more wood and wood by-products.

The achievement of thermal energy efficiency was another goal set by the design team. Several factors were taken into consideration:
(1) indoor temperature and air quality;

(2) thermal insulation;
(3) moisture control;
(4) different heating and cooling systems;
(5) passive ventilation and shading;
(6) glazed loggias acting as buffer zones;
(6) rooflights being used to enhance cross-ventilation for the one-level house



(a) *Shading is achieved by the projection of the slabs onto the terraces.*



(b) Natural cross ventilation brings cooler air into the building. The glazed terraces act as a buffer zone.

Fig. 6.89 – Affordable house, shading(a) and ventilation(b) system

The innovative aspect consists mainly in the application of industrial building technologies to a house project. The basic assumption is that an affordable house, instead of experimenting with materials which have no track record, should rely on standard technology, affordable to most of the builders. None of the technologies used, is new. On the contrary, such technologies are currently used on commercial projects all over the country.

The overall design concept incorporates several building technologies currently used in Romania:

- cast in place reinforced concrete for foundations and slab;

- steel main frame structure;
- trapezoidal steel plates for floors and roof;
- wood or steel stud secondary structure;
- double glazed loggias with PVC or aluminum frames.

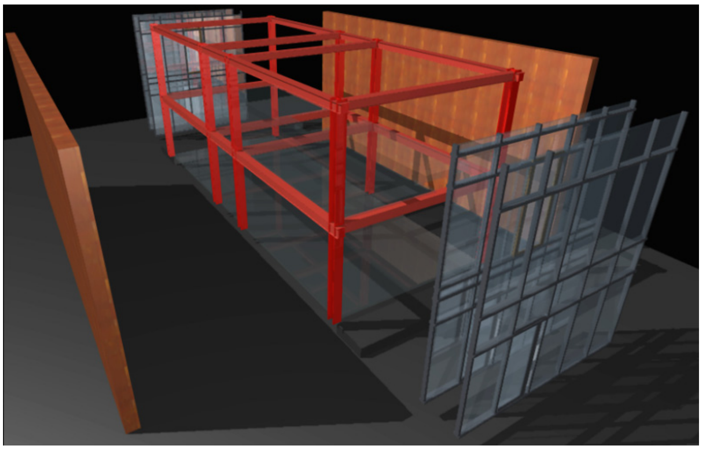
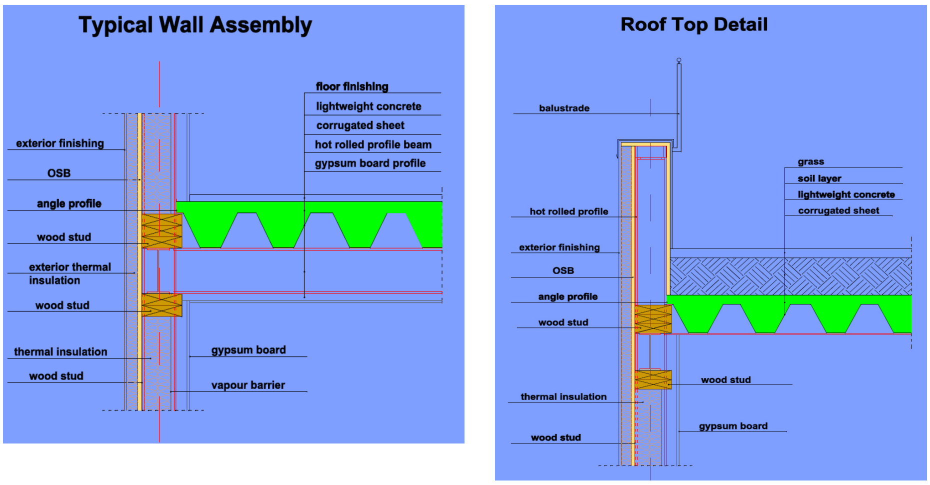


Fig. 6.90 - Schematic view of building components

Our previous experience in designing and building steel stud framed houses, shows that understanding the project and realizing the assembly of components on site can lead to significant losses of money and time. For this reason, the proposed design tries to optimize the ratio between factory made components and site work



(a) (b)

Fig. 6.91 – Affordable house, wall (a) and roof (b) detailing

Another one of the proposed solutions for the enclosure structure calls for wood studs, as the material is significantly cheaper than steel and does not require over qualified staff on site. Such a solution is probably easier to implement by small builders.

The design proposal could be even open to a situation in which, the steel frame, decks, etc., can be purchased (approved design package included) as a separate kit, by would to be owners who are in the position to undertake the construction for themselves.

The structure is designed considering the climatic and seismic conditions of the city of Timisoara, Romania. The loads used for the design of the structure are taken from Romanian codes, actually aligned with relevant Euro -codes.

The primary structural frame is made from hot-rolled sections (European sections: HEA for columns, IPE for beams). The primary steel structure is a two-storey portal frame structure in the transverse direction, whereas longitudinally shear walls resist horizontal forces due to wind and earthquake.

Columns are made from hot-rolled sections and are rigid at the base in the transverse direction, pinned in the longitudinal direction. The transverse girders are made from hot-rolled sections with semi-rigid beam-to-column connections, whereas the longitudinal girders have pinned ends. To withstand the horizontal longitudinal loads, the shear walls are of cold-formed steel studs clad both sides with 10 mm OSB.

The design of structural elements (columns, beams) was carried out according to EN 1993-1-1, EN 1993-1-3, EN1993-1-8 and Romanian seismic design code P100-1/2006, both for ULS and SLS. To control the floor vibrations, a deflection of L/350 was considered reasonable for a family house

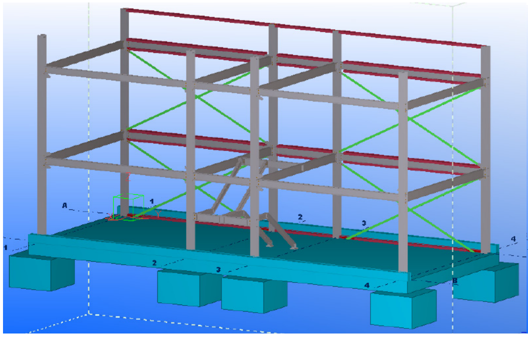


Fig. 6.92 - Primary steel structure

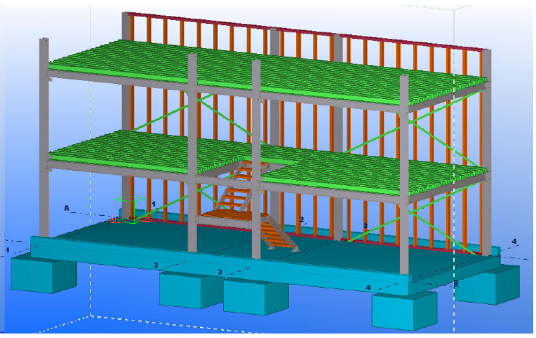


Fig. 6.93 - Trapezoidal steel decks and wood studs

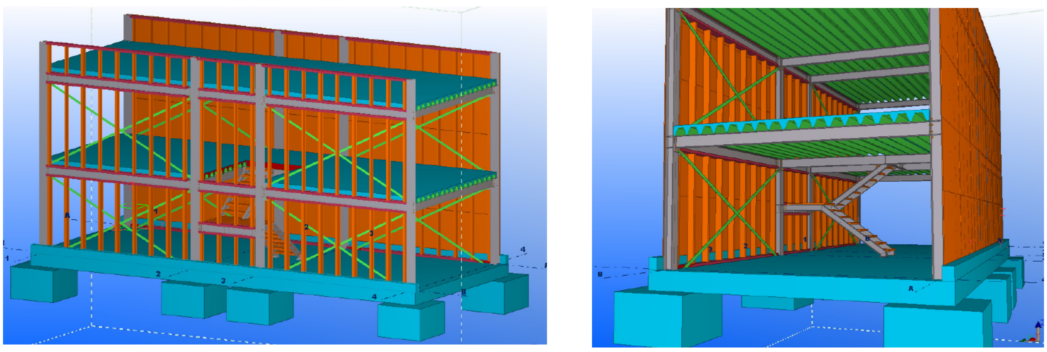


Fig. 6.94 - Complete framed enclosure wood stud walls

The performance of the shear walls is crucial for the seismic response. Test results for the full-scale wall panels made from cold-formed stud frames and the various cladding arrangements commonly used in residential buildings, tested in the Laboratory of Steel Structures of the "Politehnica" University of Timisoara, Romania, have been used as reference values for checking the available shear strength of walls.

Based on experimental results, a very simple method can be applied to calculate the efficiency of shear wall panels. Due to the fact that the structure is very regular, with planes of symmetry in both axes and distinct load paths, the analysis can be divided according to the two principal directions, i.e. transverse and longitudinal. In the transverse direction the seismic action is resisted by the portal frames, in the longitudinal direction by the shear walls.

The most important advantage of the proposed design over the traditional building methods is structural safety. Steel structures are factory made and cannot be erected without proper site inspection, which is not the case for the traditional method. In a country with seismic risk, this design feature should make a very significant difference. It is foreseeable that insurance companies in Romania, will display in the future more concern for the safety factor born out of structural design.

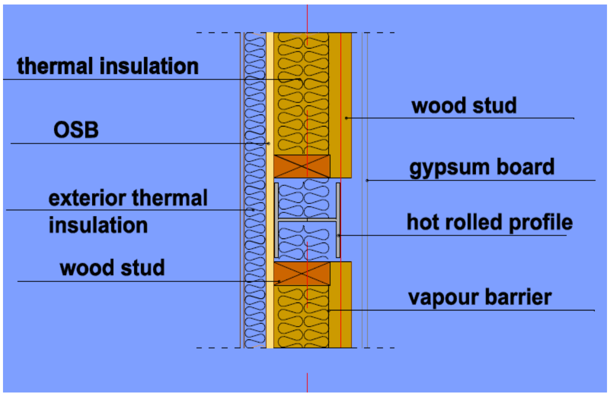


Fig. 6.95 – wall detailing

The comparative life cycle analysis for a family house presented here is designed with four different solutions, each having its own structural system, as follows: (1) hot-rolled steel framing; (2) cold-formed steel framing; (3) timber framing, and (4) masonry.

Beside the life cycle analysis at the level of the structural framework, studies regarding the cladding solution, versatility and adaptability of the four structural frames have been integrated. Several aspects are presented in turn in order to underline the impact for different stages during the life cycle: (a) construction stage only; (b) construction stage and final disposal of materials; (c) construction stage, disposal and maintenance.

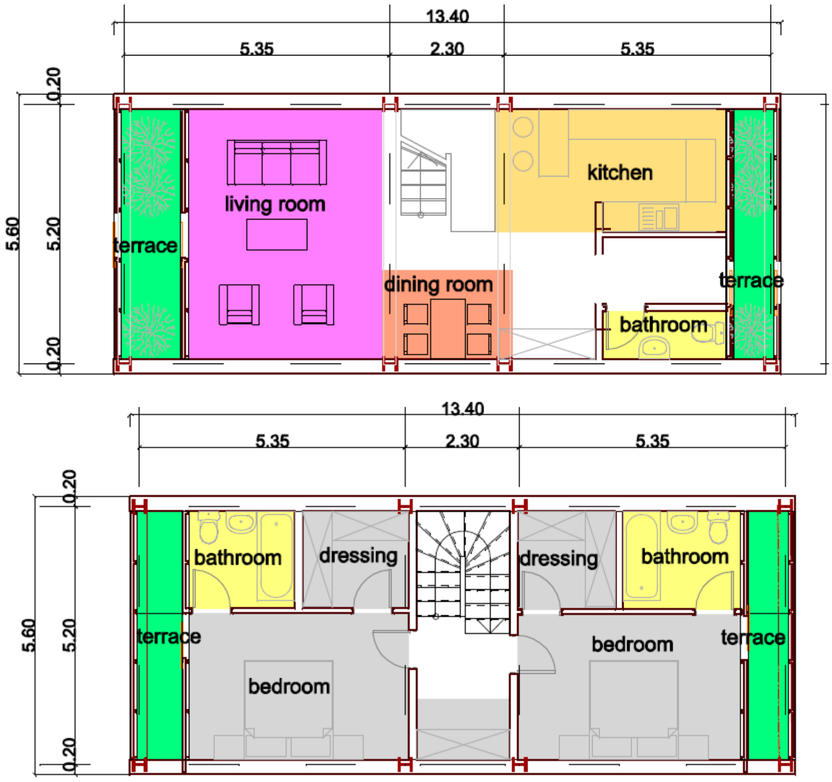


Fig. 6.96 – Affordable House, ground and upper floor

The building was designed with four different solutions, each of them having its own building system as follows:

(1) Hot-rolled steel frames: moment- resisting frames in the transverse direction, whereas in the longitudinal direction the structure is stiffened by cold-formed shear wall frames clad with OSB. The floor structure is made of lightweight concrete topping on a trapezoidal steel deck. The substructure comprises individual pad foundations connected with ground beams.

(2) Cold-formed steel framing:

In this case the construction system consisted of:

– pad foundations under columns linked by ground beams and a concrete floor slab

– cold-formed steel sections for the structural frame (C150 cold-formed sections)

– a secondary structure of cold-formed steel studs (C150 profiles spaced at 600 mm) to which OSB is attached both sides to stiffen the steel framing for lateral loads, including wind and seismic actions

– a floor structure of OSB on trapezoidal steel deck

– an envelope system and double glazed loggias with aluminium frames

– a flat roof (thermal and hydro – insulations) laid on trapezoidal steel sheeting.

(3) Timber framing, realized on the same principles as the cold-formed system. In this case the timber frame extends to the roofing. The secondary structure and envelope is built on the same principle as in the case of the cold-formed house.

(4) Masonry structure: This is the classic Romanian solution for dwellings, with hollow-brick walls 25 cm thick and polystyrene thermal insulation. The substructure system is assured by strip footings under the walls and a solid concrete slab. The floors and roof are also reinforced concrete slabs 13 cm deep.

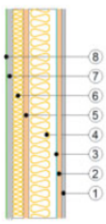
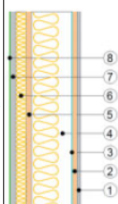
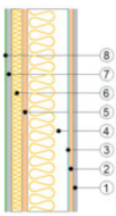
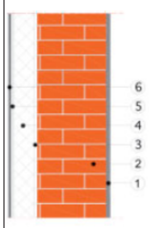
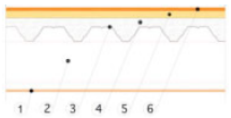
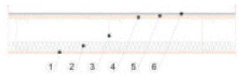
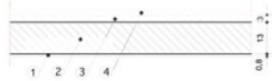
Exterior wall							
Hot-rolled		Cold-formed		Wood		Masonry	
	1. Gypsum plaster board 12.5 cm 2. Vapour barrier (foil) 3. Internal oriented strand board (OSB) 10 mm 4. Cold formed profile/ Mineral wool 50 mm 5. External oriented strand board (OSB) 10 mm 6. Rigid mineral wool 50 mm 7. Polyester wire lattice (glass fibre) 8. Exterior plastering (Silicone Baumit)		1. Gypsum plaster board 12.5 cm 2. Vapour barrier (foil) 3. Internal oriented strand board (OSB) 12 mm 4. Cold formed profile/ Mineral wool 100 mm 5. External oriented strand board (OSB) 15 mm 6. Rigid mineral wool 40 mm 7. Polyester wire lattice (glass fibre) 8. Exterior plastering (Silicone Baumit)		1. Gypsum plaster board 12.5 cm 2. Vapour barrier (foil) 3. Internal oriented strand board (OSB) 12 mm 4. Wood stud/Mineral wool 100 mm 5. External oriented strand board (OSB) 15 mm 6. Rigid mineral wool 40 mm 7. Polyester wire lattice (glass fibre) 8. Exterior plastering (Silicone Baumit)		1. Interior plastering (cement mortar) 1.5 cm 2. Masonry (bricks) 25 cm 3. Adhesive 4. Thermo-insulation (polystyrene extruded) 100 mm 5. Polyester wire lattice (glass fibre) 6. Exterior plastering (Silicone Baumit)
Intermediate floor							
Hot-rolled		Cold-formed		Wood		Masonry	
							
1. Interior gypsum plaster board 12.5 cm 2. Cold-formed profile 3. Corrugated steel sheet 4. Lightweight concrete 70 mm 5. Flooring underlay, cork plates, 3 cm 6. Finishing		1. Interior gypsum plaster board 12.5 cm 2. Thermo-insulation, mineral wool 40 mm 3. Cold formed profile 4. Oriented strand board (OSB) 12 mm 5. Flooring underlay, cork plates, 3 cm 6. Finishing		1. Interior gypsum plaster board 12.5 cm 2. Thermo-insulation, mineral wool 40 mm 3. Wood stud 4. Oriented strand board (OSB) 12 mm 5. Flooring underlay, cork plates, 3 cm 6. Finishing		1. Interior plastering (cement mortar) 0.8 cm 2. Concrete slab (concrete) 13 cm 3. Flooring underlay, cork plates, 3 cm 4. Finishing	

Fig. 6.97 – The composition of 4 types of wall structures

All four structures were designed following the above architectural plans. A detailed analysis was performed for all of these building systems and complete lists of materials were derived.

The design considers the same location for the building and the same imposed and climatic loads. The buildings were designed in such a way as to achieve a similar indoor environment.

The comparative LCA was performed using the SimaPro tool. The analyses included production of materials, construction, end-of-life of materials and a maintenance scenario for a house service life of 50 years. In order to set the input elements (inventory), both for simplifying the model and to save time, the inventory analysis was carried out according to system boundary conditions in which several aspects were considered:

– The electrical and heating systems were left out of comparison as they have the same impact in all analyses.

– Transportation was not taken into account, although the values (especially the weights) are different from system to system.

– Domestic use of the building (water/ gas/electricity) was not integrated because these values are considered to be similar.

– Energy used for construction purposes (such as cranes and other machinery) was not included into the comparison.

For the LCA, the constructive elements were considered according to the design material lists and stratification. In order to ease the input of constitutive materials in the analysis tool, they were grouped into assemblies as listed below:

– constitutive materials for substructure: concrete and reinforcing bars in foundations, gravel, sand layer, polyethylene foil, extruded polystyrene, concrete and reinforcing bars for ground floor slab

– constitutive materials for superstructure

– according to the construction system: (1) hot-rolled sections and lightweight concrete topping on trapezoidal steel deck; (2) cold-formed steel members for studs and trapezoidal steel deck; (3) timber for studs and floors; (4); masonry and concrete floors

– materials considered for secondary structure: cold-formed steel studs only for the house made using hot-rolled sections

– materials integrated into enclosures: OSB interior and exterior sheeting, thermal insulation for internal and external walls, hydro-insulations (poly - ethylene foils) etc. for timber and steel solutions; thermal system for masonry house

– materials used for finishing: finishes for exterior (render) and interior (acrylic paint) walls, gypsum plasterboard or plaster on walls and ceilings, interior doors, glazed walls, internal cold (ceramic tiles) and warm (laminated flooring) floor finishes, etc.

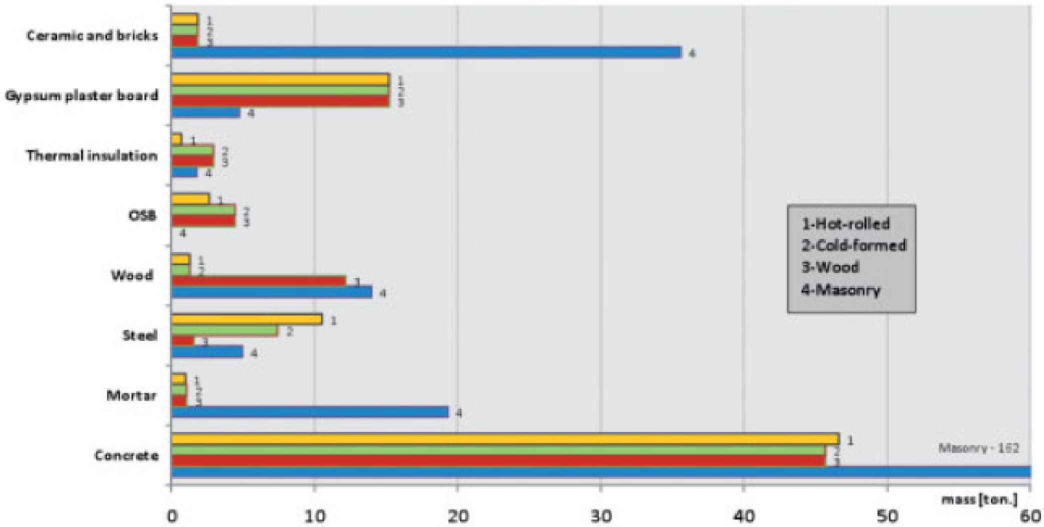


Fig. 6.98 - Calculated quantities of the main materials for the construction stage

For each structural system, the material quantities for each assembly were derived from the structural design or geometric data of the house.

Irrespective of the constructive system chosen, a building needs maintenance work during its life. These works could be of different types and in consequence could be more or less expensive and represent a very important aspect of the building life cycle. In some cases the building materials could be changed several times during the building life.

The integration of maintenance works for a structure is difficult to make in the initial stage because the predictions that might be made in advance may not correspond to a future reality. However, in order to complete the life cycle of the buildings under consideration, the following prediction (considered as pre-planned maintenance) was made, for each house, for a standard lifetime of 50 years (the design life cycle for such a construction category in Romania is between 50 and 100 years in accordance with the CR0-2005 code; a 50-year lifetime was chosen as appropriate):

– nine internal decorations (every five years)
– four changes of internal finishing (every ten years)
– four changes of roof hydro-insulation (every ten years)
– three external decorations (every 12.5 years)
– three changes for bathroom/kitchen fittings: sandstone, sanitary appliances, etc. (every 12.5 years)
– one change of the electric and heating system (every 25 years)
– one change of the roofing system (every 25 years)
– one change of the thermo-system (every 25 years).

In order to remain consistent with the boundary conditions previously explained, the main building material quantities used for maintenance were computed and are shown in the next figure.

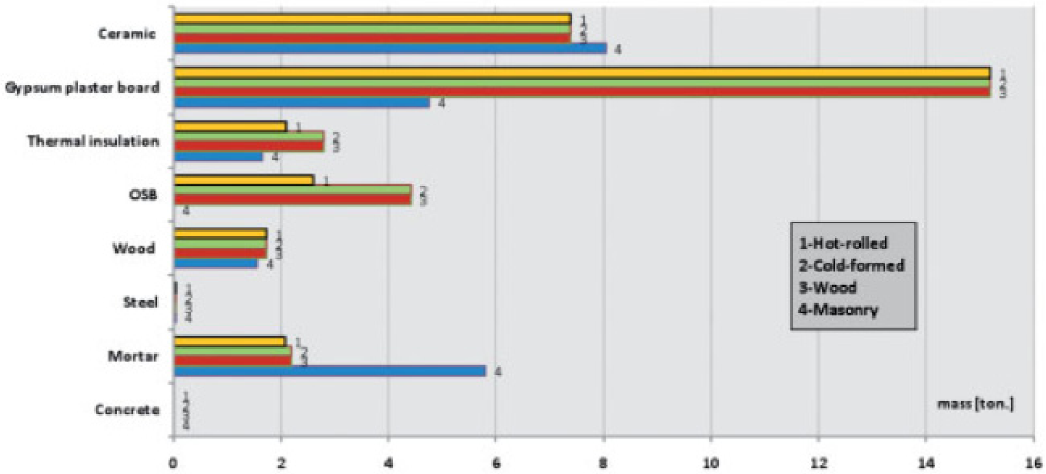


Fig. 6.99 - Calculated quantities of the main materials for the maintenance stage

It is important to notice the fact that, in case of the steel and timber structures, only the frame remains unchanged, whereas all other elements are changed at least once in 50 years. In the case of a traditional house, the maintenance is reduced here to the level of plastering for walls, thermo-system and part of the roofing system. No maintenance was considered for the substructure. However, in order to complete the life cycle assessment, the same conditions for end-of-life disposal have been considered for both construction and maintenance stages.

In a life cycle approach it is clear that the building process is not complete without an end-of-life assessment for the materials. Normally, the final destination for waste building materials represents a problem in every country, but may differ even within a country, from region to region. For the purpose of the present study, the end-of-life of integrated materials was considered according to the current conditions in Romania regarding recycling, reuse and disposal.

Building material	Reuse [%]	Recycling [%]	Burn [%]	Landfill [%]
Steel – steel sections, steel tiled sheets	–	100	–	–
Steel – reinforcement	–	80	–	20
Bricks, ceramic tiles	–	–	–	100
Structural timber – wall studs	20	–	80	–
Timber for formwork	60	–	40	–
OSB	40	–	60	–
Ballast	80	–	–	20
Concrete, mortar	–	–	–	100
Other inert materials	–	–	–	100
Other combustible materials	–	–	100	–

Tab. 6.16 The final destination for construction waste - current conditions in Romania.

The environmental impact assessment was carried out by considering the above input data for the construction phase but disregarding the common materials and processes according to the boundaries described in the previous paragraph. All the results are given in "eco-points" (Eco-indicator '99) in order to have unitary and comparable outcomes. The method used for impact analysis is Eco-indicator '99.

Considering an environmental impact analysis on different impact categories, the highest impact values result for the masonry home. This fact is also confirmed by the single-score result in which the best impact (2364 points) is obtained in case of a cold-formed house, about 40 % lower than the global score of the masonry house (3864 points).

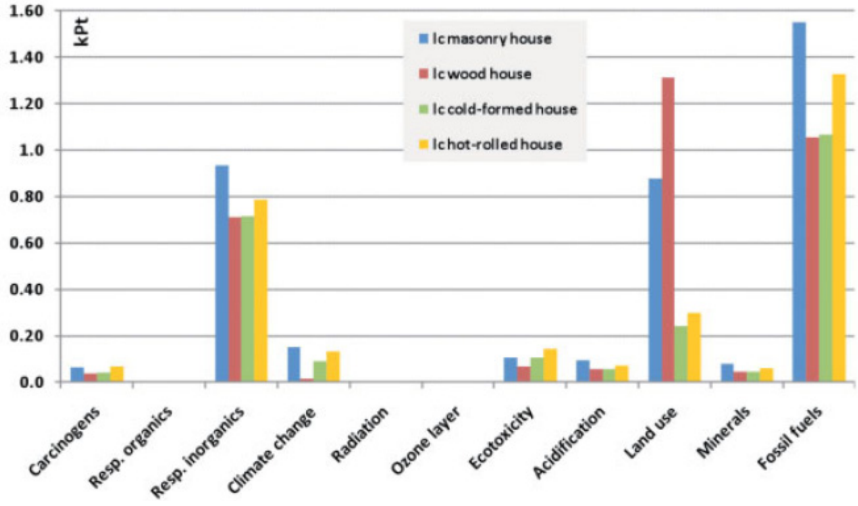


Fig. 6.100 - Comparison of environmental impact for the construction stage only (weighting)

It must be remembered that for all building systems about half of the total score can be attributed to the fossil fuels used generally in the processing of materials. In the case of timber and masonry houses a large part of the impact is due to the land use mainly attributed to the quantity of timber employed. With this exception, all the impact categories are led by the masonry house.

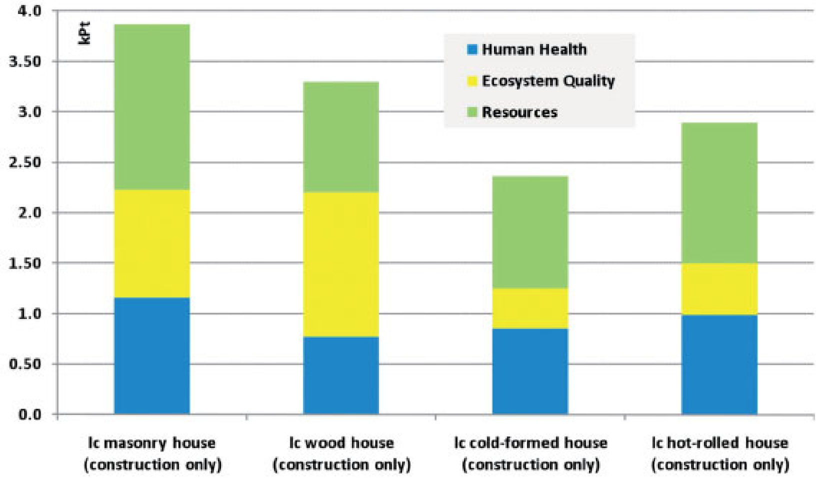


Fig. 6.101 - Comparison of environmental impact for the construction stage only (single score)

The life cycle comparison for construction and disposal scenario lead to similar results to those for the construction stage only.

Ranked by single scores we see that the masonry house affects the environment about 1.3 times more than one constructed using hot-rolled steel or a timber frame, and 1.6 times more than one constructed using cold-formed steel.

The same impact categories (fossil fuels, respiratory inorganic substances and land use) result in the greatest impact.

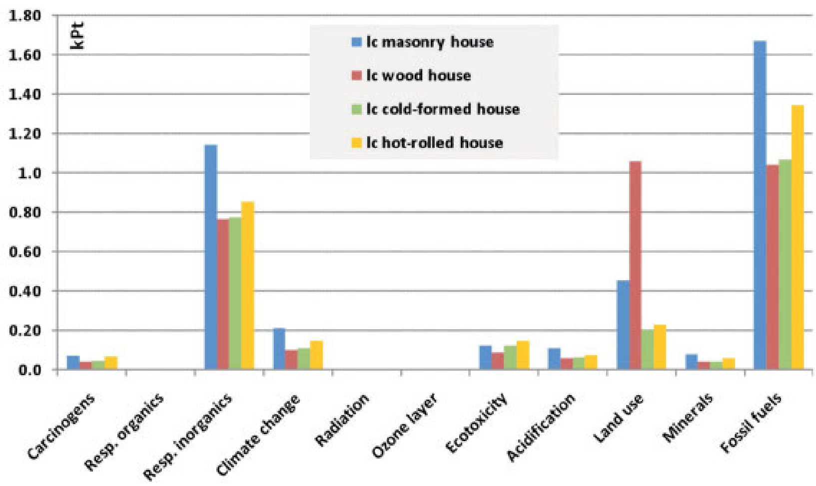


Fig. 6.102 - Comparison of environmental impact for the construction and end-of-life stages (weighting)

The final scores for the maintenance stage differ – in terms of both amount and distribution for different impact categories – from those obtained in the construction stage or end-of-life. In terms of impact categories, the same categories (fossil fuels, respiratory inorganic substances and land use) contribute more than 85 % to the total scores.

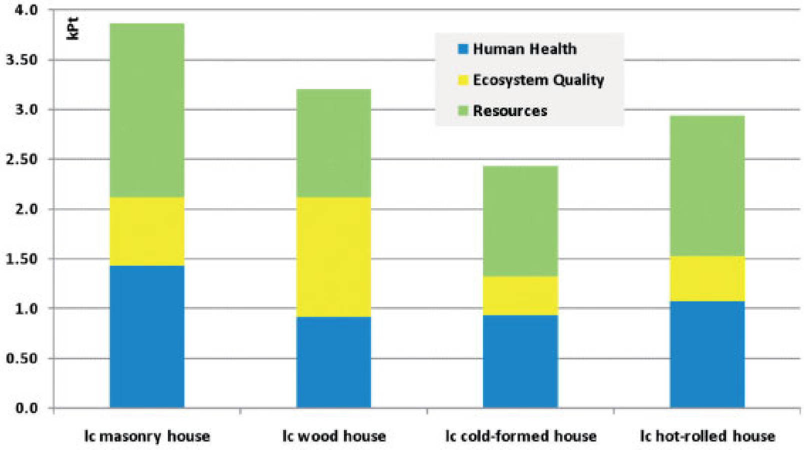


Fig. 6.103 - Comparison of environmental impact for the construction and end-of-life stages (single score)

All the values resulted from maintenance only and, cumulated in a single score, lead to small final differences for all the four systems considered. However, a difference between 3500 eco-points in the case of metal and timber houses and 3300 eco-points for the masonry dwelling was noticed. This is somehow in contradiction with the values derived for the construction process, where the ratio is reversed in the favor of the metal houses. The explanation for this derives from the fact that for the steel and timber houses, the wall, floor and roof layers are totally replaced (there remains practically only the steel/timber framework), whereas in the case of a traditional house the structure (bricks, concrete) remains as built. Moreover, it could be easily seen that maintenance plays a major role in terms of environmental impact.

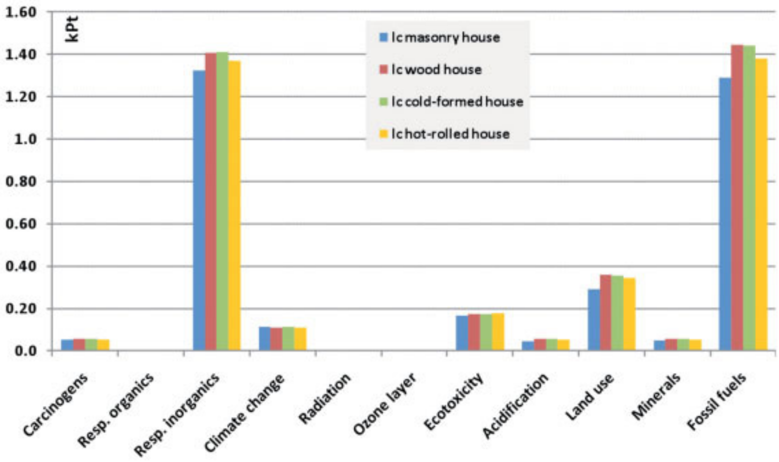


Fig. 6.104 - Comparison of environmental impact for the maintenance stage only (weighting)

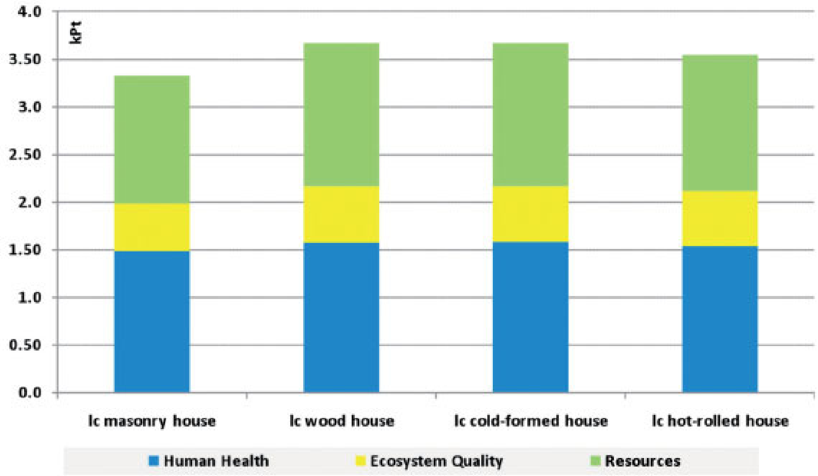


Fig. 6.105 - Comparison of environmental impact for the maintenance stage only (single score)

The scoring for all the stages of the life cycle assessment of buildings are computed as a direct sum of the construction stage, the building maintenance over a lifetime of 50 years and the end-of-life disposal for the constitutive materials.

As a general trend, the following impact categories are most affected:

(i) Fossil fuels and respiratory inorganic substances, climate change: mainly due to the manufacturing processes, which require large quantities of energy, which in turn affect the fossil fuel reserves directly. These processes contribute to a great extent to the emissions of inorganic substances and climate change gases.

(ii) Land use: due to damages caused to the land (wood exploitation, ballast pits, etc.).

Generally, the differences obtained in the life cycle analysis including maintenance follow the trend observed in the case of the construction stage only, i. e. almost all the environmental impact categories are greater for the masonry house.

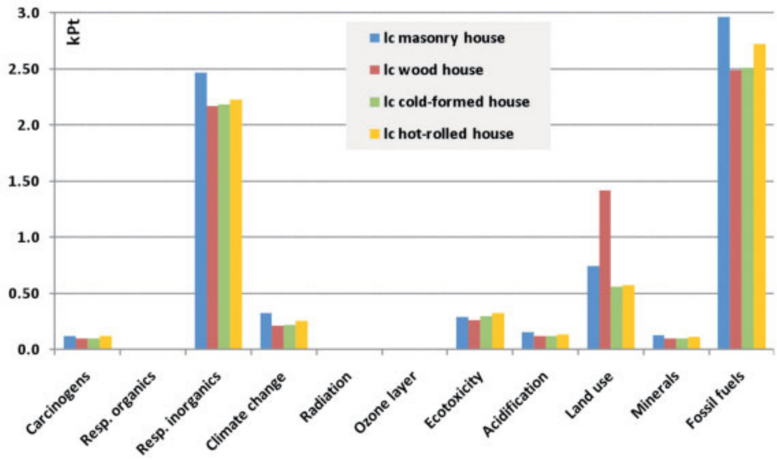


Fig. 6.106 - Life cycle comparison of environmental impact (weighting) for construction, including maintenance and end-of-life

In a single-score analysis, and taking into account the boundary conditions as explained before, the steel houses (6096 and 6481 eco-points) represent an important advantage compared with the masonry house (7192 eco-points), whereas the score for the timber house is about the average value corresponding to the impact of the other three solutions.

Of course, many parameters (such as national or regional peculiarities, climatic zones or distance from the material distributors) may affect these results. From this point of view it is essential to observe the trends and not the values given by the analyses.

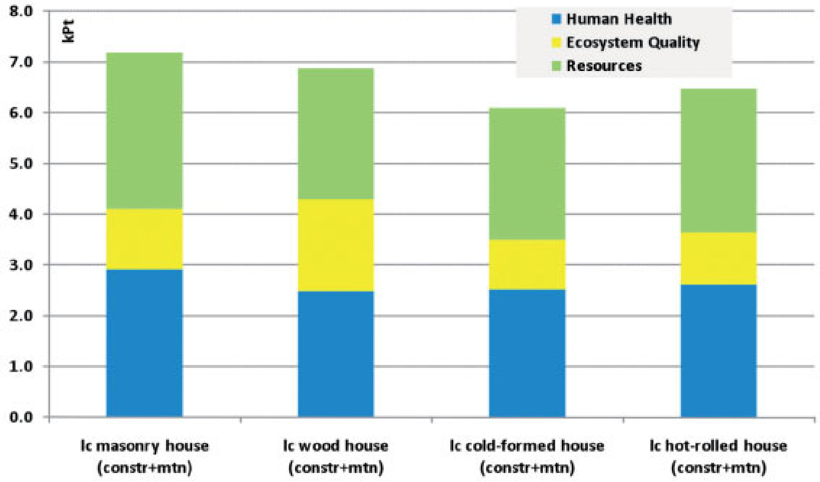


Fig. 6.107 - Life cycle comparison of environmental impact (single score) for construction, including maintenance and end-of-life

The analyses performed reveal the following aspects:

– The steel framing solutions (both hot-rolled and cold-formed) represent a good alternative to the classic masonry house, both from safety and sustainability points of view.

– All the framing solutions represent a better environmental impact for the construction stage and life cycle analyses on building materials in comparison with the classic masonry house.

– The maintenance process for steel and timber solutions is more complex than that for the masonry house. Also, it was easy to see that maintenance plays a major role in terms of environmental impact.

– There are two impact categories that lead the global impact score of the systems analyzed: (i) fossil fuel due mainly to the processing of raw building materials, and (ii) land use, in the case of houses using considerable amounts of timber in the building process. In fact these impact categories show practically the directions that should be followed for achieving a limited environmental impact.

Moreover, the innovative structure/envelope solution enables flexible floor plans and modular construction, faster fabrication and erection times and high solution diversity for floors and envelopes, having the advantages of functional and aesthetical architecture, modularity and adaptability, enhanced structural performance, particularly for seismic action and cost-effectiveness.

The seven residential examples presented, designed by a team Romanian architects and structural engineers, examples of which five are built and inhabited, proves that the construction methods presented in this thesis can be successfully implemented on the Romanian construction market.

Economics

	Euro	Euro /sqm
Materials:	36,998	246.65
Labour:	11,377	75.84
Electrical, heating, plumbing and sanitary (incl. labour):	8,000	53.33
Total:	56,375	375.83
Gross profit at 4%:	2,255	15.03
Builder's price:	58,630	390.86
VAT:	11,140	74.26
Grand Total:	69,769	465.12

Tab 6.17 Economical evaluation of the construction budget

Economic evaluation starts the construction budget for the house alone.

Nevertheless, the total investment cost for the property has to include the price of land (price of the land depends on the location), utilities, landscape features, design and legal fees as well as applicable taxes. For an actual economic evaluation, all this parameters have to be introduced in the equation. The difficulty is that, usually, the comparison yardstick on the market is only the builder's selling price/sqm. That's why putting together a complete financing package from the start, it is a challenge.

The demand for mortgage loans increased slightly in the third quarter, aided by the First Home scheme which failed to provide a strong stimulus to the market and hence made little difference.

The "Prima Casa" ("First House") program aimed at helping young people and young couples to acquire a home. For a 60,000€ loan, the program is directed only to certain segments of the population, with monthly incomes above 4,500 lei (approx. 1,000€). The eligible situations are:

- Individuals who do not have a home (e.g. apartment or house), individually or jointly with their spouses or other persons, regardless of how this property was acquired;
- Persons who are not in place a mortgage;
- Individuals or families who meet the conditions imposed by donors;
- People able to pay in advance at least 5% of the purchase price of the house, if the price is less than or equal to 60,000€, e.g. 3,000€. In case the price of the house is higher, then 3,000€ plus the difference between the purchase price of property and 60,000€. The maximum reimbursement period is 30 years;
- The interest rate applied to the loans granted through this program is variable, namely: ROBOR 3M + 2%, for the loans in lei and EURIBOR 3M + 3,75% for EUR.

Comparison with traditional housing concept and material

The proposed architectural design is versatile to the point that it can evolve to either towards a modern or vernacular expression. The difference when compare with a traditional house is more of technological nature than morphological ones.

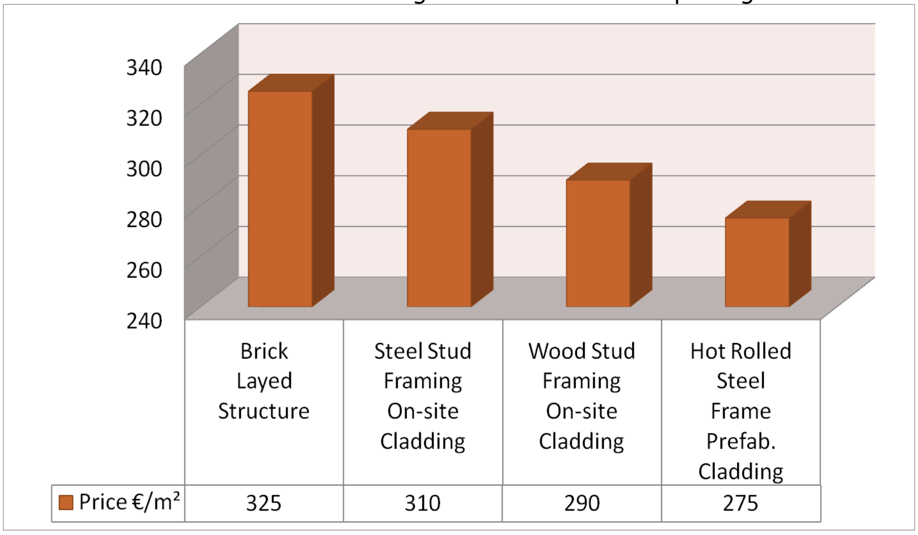


Fig. 6.108 - Comparative Construction Costs for the Proposed Design Foundation, Structure, Envelope and Labor 60% of Total Construction Cost/ summer 2008

In respect to architectural form and expression, the solutions presented here show that the concept is adaptable to a variety of urban and suburban configuration, i.e.: flat roof, pitched roof, variation of color palette etc.

Achieved cost reduction

Cost reduction has to be compared with a traditional housing concept having the same size and morphology. While discussing cost reduction is paramount to recognize that a traditional house built to the same standards as the proposed design, comes to a higher price than the current offer on the market.

The 400€/sqm. price represents actually a low price for a house located in an urban area, even for a traditional solution. On the other hand, it is difficult to imagine a traditional house at such a price of a comparable quality as the one achieved by the present project.

Social advantages

The proposed design, detailed for a unit of 150 sqm. is intended to address young couples, couples with one, two children, or couples with their parents. The living area is large enough to accommodate more simultaneous activities. The one storey unit of 75 sqm. addresses primarily the young couples as a first home.

The possibility to erect the house into two phases : *Phase 1:* house type 1 designed to support structurally another floor; *Phase 2:* addition of a new floor) encourages young families to benefit for attractive financing program to build new homes.

If we were to go further into urban planning, one could envisage neighborhoods made of such affordable houses, which could concentrate a younger population which in turn could support a range of retail outlets and services.

Possible deployment

As explained , the financing package for an affordable house, according to the present project, could be covered by the **"First home" program (Programul "Prima casă").**

A most important issue is land acquisition. Given the selling price of land plots before 2009, followed by the sharp decrease, one could expect a slow recovery. Going prices for land plots today, are 30-40% lower than before 2009. Even though, for a young couple, land acquisition, becomes a big problem, as banks do not finance it.

A system which was and is still used is to build on concessioned land with an agreement for 50 years, renewable another 49.

Providing an appropriate location and a financial package, the construction of the prototype becomes available and will definitely be the necessary step leading to implementation of the project.

Possibility for demonstration

Following the idea of building on concessioned land, a reasonable way to demonstrate the concept, would be to build show-homes in the new planned developments, built either by the financing party or by the one owning the land, or by both, as an incentive to buy the product.

6.9. Conclusions to Chapter 6

The analysis of the application and of the case studies are in fact real construction projects of which 5 are built to date.

The working hypothesis for each of them is in fact the set of functional project requirements typical for average low rise residential.

The 4 applications are presented in view of their potential to validate the use of steel structural framing for different architectural solutions. Out of the 4 applications, one uses light weight steel stud framing and the other 3 combined steel and timber structural systems.

The comparison of the 4 applications shows that the use of hot rolled steel framing combined with timber as secondary structure, allows for greater flexibility of layout arrangements and architectural expression than the light weight stud framing system.

The case studies presented further in this chapter, validate the use of steel structures in low rise residential design.

The following conclusions can be underlined after the analysis of these case studies:

- functional and flexible architectural layouts ;
- versatile architectural expression;
- enhanced structural safety and robustness, particularly for seismic action (practically complete prevention of collapse);
- adaptability of the structure to various envelope solutions;
- cost effectiveness;

– low-to-moderate environmental impact compared with traditional technologies (e.g., masonry and/or concrete).

The comparison of steel framed houses with traditional masonry wall construction, shows a better rating for the first and therefore qualifies them for sustainable development applications.

The thesis objective was to illustrate the advantages of using steel structural framing for low residential buildings. This objective was selected given the shear proportion of detached and semi-detached houses within the construction sector. As Eurostat statistics show, each year more than 20 000 people self build a new home - 10% of all new houses built. In Europe 60 per cent of new properties may be self built. And with the growth in self build increasing there is no reason why you could not. It no longer requires the inside networking that it did 10 years ago with full packages available - from turn key homes through to mortgages specifically for self build homes.

The self built homes amount for about half of total residential units erected in Europe and that means that in fact, owners are coming to the forefront of building decision making. Combined with the new sensitivity for ecological issues, this leads us to think that a lot of the input for low-energy building design will come not only from architects and engineers, but from the owners themselves.

7. Conclusions

1. Metal houses and the residential sector

The first applications of metal frames to residential projects can be traced back to the first half of the 19^{th} century, at the time of the first industrial revolution. Initial cast iron elements and framing, was gradually replaced with steel. This is to say that metal framed houses without representing a sizeable part of the market, are not a complete novelty.

2. Continuity of residential design challenges in time

The constant evolution of living conditions has a direct influence on the architectural layout. In the same time, from the primitive dwellings to the contemporary houses, observing the three Vitruvian principles of *firmitas, utilitas*, and *venustas*, continue to be the key equation to solve in any design process. Residential building design retains therefore the central role in finding out economically balanced solutions.

3. Steel provides performant structural solutions

The use of steel in residential construction confers a great degree of design elasticity to practically every solution. The presence of steel in the structural component itself can be of 100% or less, if combined with wood, with direct effects on construction costs. Further, steel framing can be combined much easier with various types of building envelopes, than traditional wall masonry structures.

Steel as a construction material, plays an important role as a component for buildings and engineering structures, and it has a wide range of applications. On the other hand, steel is the most recycled material, and from the total production in the world, almost half is obtained from waste material.

The review of the steel construction sector's current position has demonstrated that:

• Steel construction is efficient, competitive and makes a significant contribution to the national economy.

• Buildings can be rapidly constructed using steel based components that are efficiently manufactured off-site and therefore are of high quality and with few defects.

• Steel framing and cladding systems, in association with other materials, encourage the design of buildings with low overall environmental impacts.

• Steel-based construction systems provide flexible spaces which can be easily modified and adapted.

The life of the building can be extended by accommodating changes in use, layout and size.

• At the end of the useful life of buildings, steel components can be dismantled relatively easily. Reclaimed steel products can be reused or recycled without degradation of properties.

• Off-site manufacture promotes a less itinerant workforce. This tends to increase safety, promote stability in the workplace, encourage skills development and foster good local community relations.

4. Steel enhances architectural design

The state of the art examples presented throughout the thesis as well as the case studies, demonstrate the great potential steel has in finding very adaptable building solutions and in enhancing architectural expression.

5. Steel as a tool for sustainable development

Through the use of steel framed building systems for the low rise residential sector, urban growth can be achieved through sustainable construction. Steel framing, therefore constitutes an important tool in the implementation of sustainable development policies worldwide.

6. Viability of the concept

All of the conclusions above, based on both theoretical research and field applications (case studies), conduct to the idea that the structural system discussed here is a viable one, both technically and economically, and that its implementation on a larger scale constitutes a practical direction for sustainable development for years to come.

Author's Contributions:

1. The synthetically review of the general context of sustainable construction followed by the critical analysis of trends in low energy residential building design

2. The critical analysis of architectural design solutions for steel framed houses.

3. The integration of architectural design with structural engineering and building physics into a integrated design process, controlled by sustainable development parameters.

4. The main contribution is the design and site work, for the 7 case studies, characterized by specific architectural and structural solutions, with various types of building envelope, which demonstrate the validity of this thesis' subject.

The specific architectural and structural solutions designed and implemented in the case studies, represent in almost all cases pioneer work in this field in Romania.

The contributions in this thesis have been published and disseminated by means of scientific articles and within research projects, as follows:

[1] D. Dubina, V. Ungureanu, ***M. Mutiu***: *Sustainable building structures for housing*. International Conference on Sustainable Buildings 2007: Sustainable Construction. Materials and Practices, Vol. 2, pp. 1096-1103, ISBN: 978-1-58603-785-7, IOS Press, Lisabona, Portugalia, 12-14 septembrie 2007.

[2] D. Dubina, V. Ungureanu, ***M. Mutiu***: Sustainable mixed building technologies applied to residential buildings: some Romanian examples. Cost C25 - Proceedings of the first Workshop: Sustainablility of Constructions, Integrated Approach to Life-time Structural Engineering, pp. 3.93-3.102, ISBN: 978-989-20-0787-8, Lisabona, Portugalia, 13-15 septembrie 2007.

[3] V. Ungureanu, ***M. Muţiu***, D. Dubină: *Soluţii constructive pentru clădiri de locuit compatibile cu conceptul de dezvoltare durabilă.* Acta Technica Napocensis. Section: Civil Engineering – Architecture. Proceedings of the International Conference – Constructions 2008, 9-10 May 2008, Cluj-Napoca. Nr. 51, vol. 1, 2008, pp. 451-460. ISSN: 1221-5848.

[4] C. Arghirescu, ***M. Mutiu***, D. Dubina, V. Ungureanu: *Sustainable Block of Flats: A Romanian Example*. 1st International Exergy, Life Cycle Assessment, and Sustainability Workshop & Symposium (ELCAS) 4 - 6 June, 2009, Nisyros – Greece, ISBN: 978-960-243-663-9, pp. 141-148.

[5] Dubina D., Ungureanu V., Ciutina A., ***Mutiu M.***, Grecea D.: Innovative sustainable steel framing based affordable house solution for continental seismic areas. Proceedings of the First International Conference on Structures and Architecture, ICSA 2010, Guimaraes, Portugal, 21-23.07.2010, p. 367-368+CD.

[6] Dubina D., Ungureanu V., Ciutina A., Tuca I., ***Mutiu M.*** Sustainable single family house - case study. Proceedings of the International Symposium "Steel Structures: Culture & Sustainability 2010". 21-23.09.2010, p. 603-612.

[7] Dubina D., Ungureanu V., Ciutina A., Tuca I., ***Mutiu M.***: Sustainable detached family house - case study. Journal of Steel Construction. Design and Research. (3)2010, 154-162.

[8] Programul international COST C25: "Sustainability of Constructions - Integrated Approach to Life-time Structural Engineering"; perioada 2006-2010. Beneficiar: Fundaţia Europeana pentru Ştiinţă ESF.

[9] Proiectul Affordable House Project, perioada: 2009-2010, Beneficiar ArcelorMittal Liege Research.

Annex - 1

AFFORDABLE HOUSES PROJECT

PRE DESIGN PHASE – WP1

Submitted by:

Prof. Dan Dubină, Ph.D., C.Eng.
Mihai Muţiu, Arch., O.A.R.
Assoc. Prof. Viorel Ungureanu, Ph.D., C.Eng.

The "Politehnica" University of Timişoara, Romania

Table of Contents

D1.2. Traditional housing concept

D1.2.a. Geographical, geotechnical, structural, architectonic constraints
D.1.2.b. Overview of Legislations and of boundaries (thermal, acoustical, seismic).
D.1.2.c. Description of the traditional housing concept (by macro-region if necessary)
D1.2.d. Advantages and disadvantages of the traditional solutions (by macro-region if necessary)
D.1.2.e. Cost of traditional housing concept (by macro_region if necessary)

D.1.3. Innovative concept
D.1.3.a. Technological state of the art
D.1.3.b. Review of affordable housing concepts in your country/region
D.1.3.c. General description of the innovative process, solution, choices and related reasoning and justification.
D.1.3.d. Advantages and disadvantages
D.1.3.e. Innovative aspects
D.1.3.f. Review of the selected technical solutions (if a decision has been made)
D.1.3.g. Preliminary architectural project) plan of the floor/s or main floors, sections, views)
D.1.3.h. Preliminary structural project and design;

D.1.4. Follow up

D.1.4.a. General Planning

D.1.4.b. Future activities planned within WP2

D.1.4.c. Critical points and risk analysis

D1.1: Socio-economic evaluation

D1.1.a. General description of the country

With a surface area of 238,391 square kilometers (92,043 sq mi), Romania is the largest country in southeastern Europe and the twelfth-largest in Europe.

Romania's terrain is distributed roughly equally between mountainous, hilly and lowland territories.

Owing to its distance from the open sea and position on the southeastern portion of the European continent, Romania has a climate that is transitional between temperate and continental with four distinct seasons. The average annual temperature is 11 °C (52 °F) in the south and 8 °C (46 °F) in the north.

Spring is pleasant with cool mornings and nights and warm days. Summers are generally very warm to hot, with summer (June to August) average maximum temperatures in Bucharest being around 28 °C (82 °F), with temperatures over 35 °C (95 °F) fairly common in the lower-lying areas of the country. Minima in Bucharest and other lower-lying areas are around 16 °C (61 °F), but at higher altitudes both maxima and minima decline considerably. Autumn is dry and cool, with fields and trees producing colorful foliage. Winters can be cold, with average maxima even in lower-lying areas being no more than 2 °C (36 °F) and below −15 °C (5.0 °F) in the highest mountains, where some areas of permafrost occur on the highest peaks.

Precipitation is average with over 750 mm (30 in) per year only on the highest western mountains — much of it falling as snow. In the south-center parts of the country (around Bucharest) the level of precipitation drops to around 600 mm (24 in).

D1.1.b. General description of the socio-geographical-economical conditions

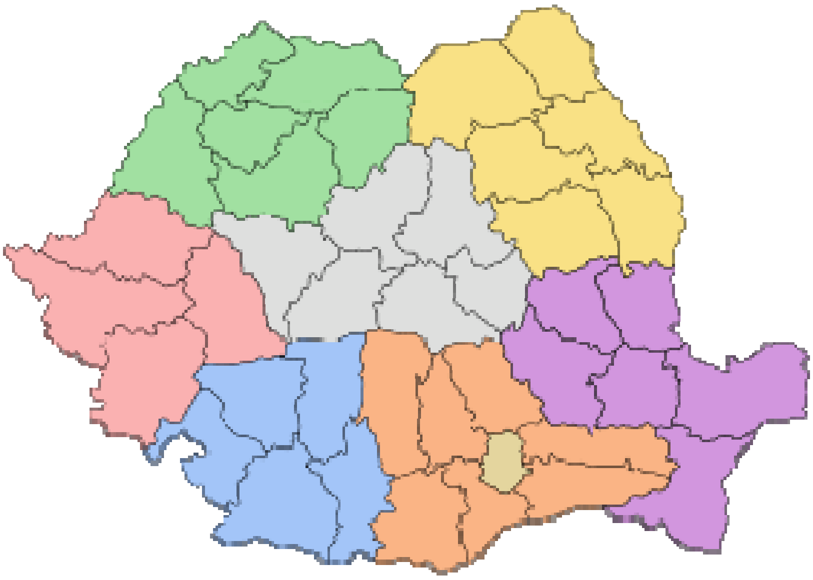
Romania is divided into forty-one counties , plus the municipality of Bucharest - which has equal rank. Each county is administered by a county council, responsible for local affairs, as well as a prefect, who is appointed by the central government but cannot be a member of any political party, responsible for the administration of national (central) affairs at the county level.

Bucharest is the capital and the largest city in Romania. At the census in 2002, its population was over 1.9 million. The metropolitan area of Bucharest has a population of about 2.2 million. There are several plans to increase further its metropolitan area to about 20 times the area of the city proper.

There are 5 more cities in Romania, with a population of around 300,000 that are also present in EU top 100 most populous cities. These are: Iaşi, Cluj-Napoca, Timişoara, Constanţa, and Craiova. The other cities with populations over 200,000 are Galaţi, Braşov, Ploieşti, Brăila and Oradea. Another 13 cities have populations over 100,000.

At present, several of the largest cities have a metropolitan area: Constanţa (550,000 people), Braşov, Iaşi (both with around 400,000) and Oradea (260,000) and several others are planned: Timişoara (400,000), Cluj-Napoca (400,000), Brăila-Galaţi (600,000), Craiova (370,000), Bacău and Ploieşti.

The 41 counties and Bucharest are grouped into eight development regions corresponding to NUTS-2 divisions in the European Union.



Prior to Romania's accession into the European Union, these were called statistical regions, and were used exclusively for statistical purposes. Thus, albeit they formally existed for over 40 years, the regions are publicly news. There are proposals in the future to cancel county councils (but leave the prefects) and create regional councils instead. This would not change the nomenclature of the country's territorial subdivision, but would presumably allow better coordination of policy at the local level, more autonomy, and a smaller bureaucracy.

D.1.1.c. Statistical data about the growth of the country, of the population,
of the construction market.

The World Bank forecasts a 4% economic decrease for Romania in 2009. For the next year, the estimates show 0.5% increase in GDP, - whereas for 2011, the GDP is expected to increase by 2.5%.

"Global Development Finance 2009" report goes on to underline the current account deficit, which is estimated to reach 8.4% of the GDP, against 12.4% of the GDP, its value for the last year. The figure is expected to drop to 7.5% in 2010, only to see it increasing again in 2011 to 8.7%.

Regarding the Central and Eastern European economies, the World Bank expects to see a 1.6% economic shrinkage in the region in 2009, followed by GDP stagnation in the course of the following year.

Among the most important risks in the region, the World Bank indicates foreign capital flux crash for all emergent economies, serious economic activity deterioration and a big reduction in demand, both for exports and for imports.

The World Bank has now a different forecast that it had in February, when it saw the Romanian economy increasing by 0 to 2%. The "Global Economic Perspective in 2009" report presented in December 2008 predicted a 3.2% economic growth in Romania.

The International Monetary Fund (IMF) anticipates a similar 4.1 % Romanian economy decrease in 2009, while the European Commission forecasts a 4% reduction. Both institutions appreciate that Romanian economy will stagnate in 2010.

Romania's GDP contracted by 6.4% in the first quarter of 2009*,* compared to the same period last year and, by seasonally adjusted data, by 2.6% over the fourth quarter, according to INS, and the economy entered into technical recession.

Technical recession is defined as a decrease in GDP, seasonally adjusted, in two consecutive quarters, as against the previous quarters. "In the first quarter of 2009*,* gross domestic product decreased by 2.6% (seasonally adjusted data), as compared to the fourth quarter of 2008*,* and by 6.4% over the first quarter of 2008 (non-adjusted data), reveal the flash data in the INS release. According to estimates based on seasonally adjusted data, in the second and third quarters of 2008, GDP increased by 0.3%, 0.4%, respectively, as against the previous quarter. According to INS, in the fourth quarter of 2008*,* the GDP registered a 3.4% decrease, as against the third quarter.

The GDP drop in the first quarter of this year, as compared to same period last year, exceeded analysts' expectations by far, as they had expected a 2-4.1 % economy contraction. In the fourth quarter of 2008*,* economy advanced by 2.9%, compared to same period last year.

According to the 2007 census, Romania has a population of 22,276,506 and, similarly to other countries in the region, is expected to gently decline in the coming years as a result of sub-replacement fertility rates.

Age structure:

- *0–14 years:* 18% (male 2,111,320; female 2,015,347)
- *15–64 years:* 68% (male 7,597,958; female 7,707,498)
- *65 years and over:* 14% (male 1,237,368; female 1,741,630)

Romania has a higher proportion of young adults in its population than any other Western country except Slovenia. 8.55% of the Romanian population was born in the period from 1976 to 1980, compared with 6.82% of Americans and 6.33% of Britons.

Urban-rural ratio:

- Urban — 55.20%
- Rural — 44.80%

Population growth rate:
The population growth rate is -0.127% (2007 estimate).
In common with many Eastern European countries, Romania has experienced a decline in population in recent years. The population fell by 1,129,000 or 4.95% in the decade 1992–2002.

The construction industry is estimated to be worth approximately €14bn in 2009, which marks a significant loss when compared with 2008's worth of US€16.2bn. It is expected that the positive growth will resume in 2010, but still at a much slower pace than in previous years.
Residential construction - both new and remodeling – represents the lifeblood of Romania's construction sector. Market statistics and forecasts demonstrate a vibrant market with plenty of potential for new growth.
Real estate market transactions faced a sharp decline in the last quarter of 2008, and the prices for some segments decreased, especially for land and residential buildings. But on the other hand, new opportunities appear in the market given the lower priced assets and costs that might attract new comers that have stood aside up to now.

Local responsibility for running sizeable projects

When state funded, sizeable housing projects as the ones run by the ANL (National Housing Agency), the participation of local authorities is limited to providing the land for the development. Other than that, local authorities are involved in various stages of the project, would that be during the approval and bidding processes, or during the construction period.
Except for the local offices of ANL, no other state agency is involved in sizeable housing projects.

D.1.1.d.Description of the construction market: main materials, main construction types, main builders, structure of ownership, structure of the decision making process, peculiarities

Main materials

The traditional construction method uses the following materials:

- Load bearing brick masonry/cement mortar;
- Cast in place reinforced concrete foundations, slabs and framing;
- Acrylic stucco exterior finishings;
- Polystyrene wall cladding;
- Mineral wool loft insulation;
- Square section wood roof framing;
- LAF (low admittance fluids) foils;
- A variety of roof tiles: clay, steel, concrete, asphalt shingles;
- PVC framed windows with thermo pane glazing;
- Gypsum board for interior wall construction;
- A variety of finishing materials

Typical traditional construction method

Other than the traditional construction system, several new technologies based on wood or steel sections as framing materials are being implemented, without competing for the moment, in terms of volume of sales, with the traditional method.

These new technologies are using, in addition to the materials described above, the following:

- Trapezoidal steel plate for Q decks
- OSB (oriented strand boards) sheets;
- Single ply membranes for water insulation;

Main construction types/residential

Houses

One level + loft or two level houses
reinforced concrete structural frame, floors and foundations
brick load bearing masonry or/and brick infill

wood roof framing
thermo pane glass/ PVC framed windows
polystyrene wall cladding / 5 to 8cm

Apartment buildings:

Most commonly built apartment buildings have 4-5 levels. The structure is reinforced concrete foundations, frames and slabs, with hollow brick or light concrete blocks infill.

Lower then 4 levels apartment buildings tend to be more exclusive and are situated in better areas within the city. Collective buildings higher than 5 storeys are common in larger projects developed by strong construction companies.

Main builders

Construction / companies before 1989

It is worth saying a couple of words about the situation before 1989, as it still influences the market today.

Construction market before 1989 was run almost entirely by the state through a series of large construction companies, one for each county. In addition, large industrial objectives, such as hydroelectric, thermoelectric and nuclear plants, or other types of factories and plants were built by specialized state companies such as ARCOM, Trustul Carpati, etc.

Twenty years later, these large companies, after undergoing the process of privatization, melted down to form smaller private own companies.

The housing sector, before 1989, was financed almost entirely by the state. The principle was to provide free housing in collective apartment buildings, ranging from 5 to 11 levels. This situation was common to all urban areas.

Few private homes, and apartment buildings/4-5 level condominiums/ were built during this time in urban areas.

In the rural areas private home building was less restrictive before 1989 and was done according to the local/traditional methods.

Construction/ companies after 1989

There were many small and medium sized construction companies active on the housing sector. As money became more ready available, starting in 2005, some larger construction companies previously involved in commercial projects, such as malls or large retail outlets, switched to the housing sector as well. By the end of 2007, after two years of continuous growth, the price for a new apartment ranged between 1000 – 1500 €/m^2 with standard finishings.

Structure of ownership

In the early 90's, as a measure to shelter the population against the foreseen tough economic readjustments ahead, the state gradually sold its entire housing property, apartment by apartment, at prices which towards the end of the decade due to inflation, were highly undervalued.

This explains why, paradoxically enough, in Romania, the vast majority of the population (95%) owns their home, in the form of an apartment, clear title.

In rural Romania home ownership/ clear title is the common situation.

This aspect has some bearing when explaining owner mentality and the spending pattern of the population.

In fact, the first generation of home-owners didn't have to go through the hardship of paying back a 15 or 20 year mortgage. As a result, the level of expectation is still too high in respect to the average family earnings, the usually projected jump being from a 2 bedroom apartment of 60 sqm to a minimum 2 level, 150 sqm home.

This situation creates a very serious problem for those involved in designing, producing and selling a house, at an affordable price.

Structure of the decision making process

Any housing project starts with an urban planning project and development permit. According to site specifics, adjacent developments and other meaningful parameters, the approval process can last several months to several years. Once the subdivision project approved, the individual lots can be put on sale. Further, the owners embark upon the process of obtaining the building permit.

House projects in Romania have to be sealed by a registered architect, and the structural section of the project verified by an expert authorized by the Ministry of Public Works (MLPAT).

In such a way, conformity to the existing design and structural standards are theoretically met for all applications. Through the construction process, the construction site could be inspected by a number of government agencies, in order to ensure the quality of workmanship, safety procedures, etc.

In fact, most of the private homes built in Romania, are not properly checked during the construction process, especially when, the owner acts as general contractor.

Connected with this factor, insurance policies for private homes, as far as 2008, did not require the project as proof of the construction works undertaken.

Peculiarities

Housing developments in Romania are promoted mainly by land developers.

The law and the urban planning regulations allow for the selling of lots in subdivisions without providing any roads and infrastructure utilities. Even the taxes required in order to reclaim the land from the agricultural property of the state, are paid by the lot owner and not the developer.

Subdivision housing projects are more often than not, commissioned by the would to be owners, without any involvement from the developer. This is not true for the large development companies, active mainly in Bucharest.

D.1.1.e. Listing of the main player in the affordable house market (Government, NGOs, private) and of their key purchasing criteria.

The National Agency for Housing, active from 1996 is responsible for founding and guaranteeing the construction of about 20000 units both apartments and row housing.

Housing projects developed by ANL (Agentia Nationala pentru Locuinte/ National Agency for Housing), are run locally by the local council and the ANL county representative.

The local council is in charge of providing the land, from the state's propriety and to establish the eligibility for the program. On the other hand, the ANL is in charge of the bidding process, selection of the main contractor, etc.

ANL (National Housing Agency) Row Housing Development

ANL (National Housing Agency) Row Housing Development Timisoara

ANL (National Housing Agency) Apartment Buildings Timisoara

ANL (National Housing Agency) Row Housing Development

ANL (National Housing Agency) Row Housing Development

Affordable housing in Romania

In order to define what constitutes an “affordable house” in Romania, we have to start from the average earnings of the potential owners. As shown in statistics as late as June 2009, the repartition by age group of individuals with net monthly earnings above 470€ (2000 RON), is as follows:

15 – 24 years old…………..22,050 people;
25 – 34 years old…………..57,730 people;
35 – 49 years old…………..49,010 people;
50 – 64 years old…………..49,560 people.

Total………………………..178,350 people,
representing 0.8% of the total population.

Taking into consideration the earnings by couple, the percentage will certainly go up. No statistics were issued regarding couple earnings with average salaries.

Another important factor to be considered is family support, either in the form of direct financing and the provision of collaterals, or by providing the land.

The in depth analysis of the housing market potential in Romania, notably today, with so many uncertainties lying ahead, is by no means an easy task.

Affordable 130 sqm single family homes Timisoara 2005-2006

These houses built on 250 sqm lots, were sold in 2006 at a price of 65,000€ (price of land included).

Purchasing criteria

The potential owners are basically looking for:

Price
Size/ Net Surface
Construction quality
Location - neighborhood
Distance to amenities
Distance to work/Public transportation
Distance to kinder garden/schools
Noise, pollution

D.1.1.f. Define the cost of housing acceptable or desirable in your country/region. Define Low-cost housing in your country.

At the market levels of 2006-2007 (2008 is not really specific, as the prices flared up) an apartment with average finishing (not in Bucharest), sold for a minimum of 600 €/sqm. This figure could be taken as the benchmark.

As a matter of fact, 600 €/sqm plus 19% VAT, was the price most private homes were contracted, up to the last quarter of 2008. This price does not include the land or the utilities, such as access roads, power, gas and sewage.

Given the gross average income of about 300€/ month, it is obvious that an affordable price/sqm should not go above 400€/sqm.

D1.2. Traditional housing concept

D1.2.a. Geographical, geotechnical, structural, architectonic constraints

Geographical and geotechnical conditions are summarized below:

Natural Conditions	Snow Load [KN/m²]	Wind Pressure [KPa]	Frost Depth [m]	Ground Acceleration
Interval Values	1.5 – 2.5	0.4 – 0.7	0.6 – 1.1	0.08g – 0.32g

Structural constraints

Structural constraints depend on the construction materials and techniques used. In this respect, load bearing masonry walls allow for shorter spans.

Architectural constraints

The architectural constraints are the result of the structural system, which in turn depends on the construction materials and techniques used. A lot of fine homes were built with these now obsolete construction techniques, so, judging the architectural constraints requires to analyze the traditional concept as related to today's needs.

In this respect, load bearing masonry walls allow, naturally, for shorter spans, and do not provide much room for improving existing layouts. Other than that, the traditional house concept does not present serious architectural constraints.

D.1.2.b. Overview of Legislations and of boundaries (thermal, acoustical, seismic)

New subdivisions/lot sizes

A tremendous development of new subdivisions can be noticed since 1989.

In the county of Timis alone, there are about 1 million new lots, of which some of them developed. New lot sizes are usually 15x30 m, 17x35m, with the average area of 450 – 550 m^2.

The urban planning regulations require, either 1.9 m withdrawals from adjacent properties, in the case windows contained by lateral facades, or they allow the development up to the property line. The idea is to avoid narrow spaces developing between 2 houses. The front and rear set-backs from the property lines are usually about 6m.

In terms of land use development, a 30% ratio house footprint/lot size is the standard legislation for 3 level houses.

Thermal

As for now, there is no legislation applying to new residential buildings, including houses. There are though, new standards for the thermal rehabilitation of the existing apartment buildings, issued in March 19, 2009, which give a sense of what the authorities consider acceptable at the moment. The aim of the new legislation is to reduce the level of the annual requirements for energy (residential heating and cooling) at below 100 kWh/m^2.

Most of the existing houses built before 1989 have uninsulated 30 cm brick walls, with

K = 0.35 – 0.38 W/m2K.

When insulated with 5 -8 cm of polystyrene, the brick wall reaches

K = 0.20 – 0.25 W/m2K.

At this level of insulation, no significant energy savings can be made yet; the main effect is to move the dew point towards the exterior. Almost all new houses are built this way, with a rather insufficient level of insulation. Levels of K = 0.12 – 0.18 W/m^2K, can be reached only by spending enough money for thermal insulation. This brings up the question of what level of insulation is appropriate for an affordable house. In any case not less than K = 0.20 W/m^2K.

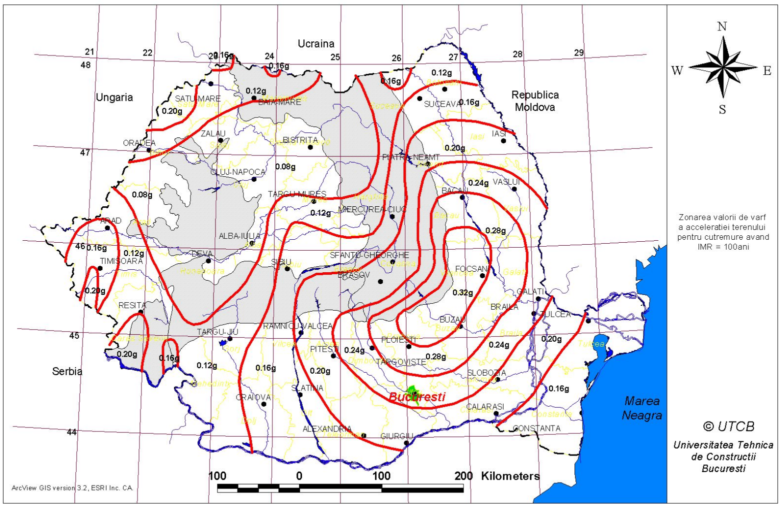
Acoustical

There is no legislation with direct application to the housing sector. The existing legislation (admissible noise levels) applies to other types of architectural programmes, such as hospitals, schools, kindergartens, etc.

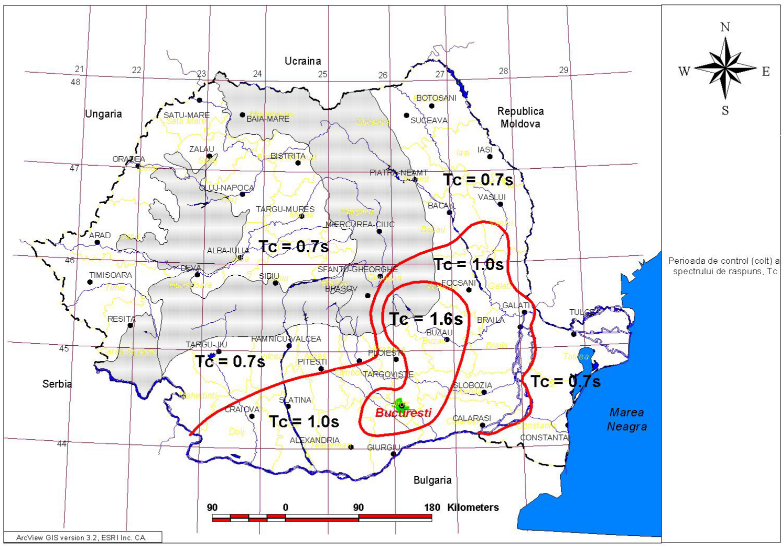
Seismic

National territory is divided in zones of constant seismic hazard. Seismic hazard for design is expressed by horizontal peak ground acceleration a_g (determined for the return period associated to ULS).

The structures have to be designed according with the seismic regions by the Romanian Seismic Design Code P100-2006. The seismic action is characterized by the following parameters $\gamma_I = 1$; $a_g = 0.08g \div 0.32g$, $T_c = (0.7 – 1.0 – 1.6)$s; q = 1.



Seismic hazard for design is expressed by horizontal peak ground acceleration a_g (determined for the return period associated to ULS)



P100-1/2006: T_C specified at a macroseismic scale

The elastic spectrum: normalized form $\beta(T)$:

- Vrancea source: T_C=0.7, 1.0, 1.6
- Crustal sources in Banat with a_g = 0.20g and a_g = 0.16g

D.1.2.c. Description of the traditional housing concept (by macro-region if necessary)

Houses built before 1948

1948 is the year of "nationalization", which in fact consisted in the confiscation of private property by the state. This event changed the course of private investment in the housing sector for the next 40 years.

In analyzing the traditional housing concept, up to 1948, a distinction has to be made between urban and rural housing concepts. In rural areas, traditional housing concepts relied mostly on wood (logs) buildings, finished with stucco, applied on reed mats support. Such buildings ranged in size from 60 – 100 m^2 and were surrounded by equally large stables.

In about 1900, in some rural areas, the wood log system started to be replaced with

load bearing brick masonry. This process continued even after 1948, as rural development was not completely stopped by the new regime.

In the region of Banat, a new building technology was introduced after 1720, by the German colonists, consisting in masonry with adobe bricks. This system proved to be very well fit to the local conditions{40-50 cm thick walls), the only great disadvantage being the foundation made out of bricks, which in time engaged the cracking of the walls (in about 100 years).

In the urban areas the houses were traditionally built with load bearing brick masonry, with wood floors and roof frames.

After 1900, the system was improved, with the introduction of reinforced concrete foundations and sometimes the slab over the basement, reinforced with steel profiles.

Double wood frame windows were the standard.

Houses built between 1948 – 1989

Characteristic for the houses built this period, is the introduction of reinforced concrete for foundations and frames. The walls continued to be made out of brick masonry, 30cm thick, with no thermal insulation.

The number of private houses built during this period is quite small, most of them being built in the rural area.

The dominant housing development during this period was the construction of apartment buildings made either of prefabricated reinforced concrete panels or poured in place reinforced concrete structures, 5 to 11 levels high. The state designed, financed and built a very large number of apartments, all over the country, starting in the 60's. This way, Romanian mentality was modeled by living in large collective house developments.

The level of expectation, in regard to building standards, can be traced back to this experience as well.

Houses built after 1989

Traditional houses built after 1989, reflect a radical change in mentality. The owners are making use again of architecture as a way to express themselves. The main characteristic of house production during this period is the never-ending search for a personalized architectural product. As a result, the large majority of the new subdivisions, lack an architectural "style".

Private houses built after 1989, present a few new characteristics, such as:

- the generalization of the second floor;
- improvement of the architectural layouts, reflecting a new lifestyle;
- the introduction of a larger living room instead of a dining room;
- the introduction of an extra bathroom;
- the introduction of new materials: polystyrene thermal insulation, steel roof tiles, thermo pane windows with PVC frames, and a new generation of equipment for electrical, sanitary and HVAC

Structurally, the 2 level houses are built with reinforced concrete foundations, slabs and frames, load bearing masonry walls, wood framed roofs. Houses are insulated with 5 – 8cm of polystyrene, which leads to a K value of 0.20-0.25 W/m^2K. Exterior finishing are acrylic stucco.

D1.2.d. Advantages and disadvantages of the traditional solutions (by macro-region if necessary)

Houses built before 1948

The houses built during this period, in any way those not older than 100 years, even with low levels of maintenance, are still in use today. This is true for brick masonry load bearing structures, mostly in urban areas. It can be said that these houses were well built and served several generations during their years in service.

From the architectural point of view, judging from the houses which survived, most of them carry a charm difficult to duplicate today.

In so far the disadvantages go, we can note the lack of seismic design and no thermal insulation other than the thickness of the wall brick.

As a disadvantage, it has to be pointed out that, structural rehabilitation of such houses is in most cases to costly to undertake, exception being the listed monuments.

In terms of architectural layouts, the old houses do not correspond anymore to the contemporary requirements.

Houses built between 1948 – 1989

The houses built during this period, benefit from the advancements in seismic design and the use of reinforced concrete, so the main advantages lay in the area of structural safety.

The architectural layouts start to reflect the changes in lifestyle.

Thermal insulation is not present at all.

The architectural style, with the exception of few examples, is dull, influenced by the style of the larger apartment buildings.

Houses built after 1989

The main advantages of the houses built after 1989 are:

- safe structural design;
- updated architectural layouts;

- personalized architectural expression;
- the use of new construction materials, energy saving measures;
- use of construction technology which does not require high skilled workers;

The disadvantages are:
- no room for flexible layouts;
- insufficient thermal insulation for significant energy saving;
- difficult to ensure quality workmanship on site;

D.1.2.e. Cost of traditional housing concept (by macro_region if necessary)

While analyzing the cost of the traditional housing concept, it is important to note the manner in which the construction is financed. The would to be owner has basically 3 options:

- to go through a general contractor, for a turn key project which allows for bank financing;
- to go through a general contractor, for some of the work to be done, usually the structure and the roofing, which limits the bank financing;
- to act as a general contractor himself, and to subcontract or do himself all the work, with his own money and/or limited bank financing.

Usually, when analyzing the market's potential, the statistics do not take into account the 3rd situation, which is by the way, the widest spread.

As a result, the cost of the traditional housing concept, as a basis for any kind of further comparison, has to be gauged most prudently.

As an example, a 200 m^2, 2 level house, could be erected between 2006 – 2009 with 55.000 € (19% VAT included) worth of materials (standard finishing), which gives 275€/m^2. The price of labor is not included, as construction work was made by the owner.

Normally, a house like the one described above could be contracted with a construction firm (up to 2008) for about 600-700€/m^2.

According to the media, the price components for a typical apartment building project are:

- cost of project, taxes, etc. 10%;
- building materials 20%;
- builder's earnings 20%;
- developer's share 50%;

(including the price of land)

This is the reason why the vast majority of would to be owners, more so in rural areas, contract the work themselves.

In other words, the market has a sizeable untapped potential, worth considering when promoting, as in this case, new housing products.

D.1.3. Innovative concept

D.1.3.a. Technological state of the art

The most common building technology currently used in Romania is brick load bearing masonry with reinforced concrete foundations, frames and slabs.

Other new technologies as:

Polystyrene insulated concrete forms

Wood framed houses, both studs and square section wood

Steel framed houses, both steel studs and hot rolled steel

The building enclosure related technologies are ready available, as they are currently used for commercial or industrial applications.

For the moment, the new technologies do not compete in terms of sales with the traditional model.

D.1.3.b. Review of affordable housing concepts in your country/region

The general meaning of an affordable house concept is a highly debatable issue. As shown above, the mentality is to jump from a 2 bedroom apartment to a two level, 150 m^2 house, with a lot not less than 500 m^2.

Some more realistic assessments emerged as the economic crisis set in.

The latest program/ June 2009/ designed to re-launch the battered building industry, is 'The First Home", destined to the first time owners.

The effective costs for the loans, in the program "The First Home", are between 5.57% - 5.74% for € and between 13.45% - 14.13% for RON.

The maximum value for the mortgage loan guaranteed by the state is 57.000 €, in the case of a home that worth 60.000 € or more. In order to obtain this sum, (for the loan in €), the minimum income for a married couple must be in between 568€ - 782€, depending on the loaning bank. The loans in RON are even harder to obtain, the minimum income for the same couple must be between 5.377 RON (1.277 €) – 6.000 RON (1.421€).

The construction of new houses is not financed by all the banks in the program, but is financed by BCR, the largest bank in the system, which estimates that from the 450 mil. € available, about 25% will be used for financing the building of new homes.

Traditional masonry with reinforced concrete foundations, slabs, etc.

This system is the most widespread, given the fact that the construction techniques are quite simple, building material affordable and the work force ready available.

Average quality construction can be achieved with average to low skilled workers.

The system is preferred by owners acting as general contractors.

One of the advantages of the system is that the construction can be stopped at any time and restarted when conditions allow. On the market, it is customary to negotiate a construction price/sqm, which includes foundations, load bearing masonry walls, reinforced concrete slabs, wood roof framing and roof tiles. The contractors usually demand 250 – 325 €/sqm to complete the phase.

Polystyrene insulated concrete forms

This construction technique is promoted locally by a number of companies, mainly polystyrene form producers. One of the companies active on the market is Amvic. We have no data about the price/sqm for this method.

Wood structure houses

Wood framed houses are made with both studs and square section wood. There are several companies which prefabricate some of the construction components. The price range is about 290 – 300 € /sqm, without foundations and finishing.

Steel structure houses

Even though Romanians are not to keen in buying steel structure houses, some progress has been made in promoting the product on the market.

Two main systems are being promoted currently:

- The first is using square sections to manufacture trusses which are assembled to form the structural system;
- The second uses cold formed light gauge steel profiles, assembled in the manner of the wood studs, to form a structural system

Two companies stand out in promoting these systems, ArcelorMittal Construction and Lindab.

ArcelorMittal Construction

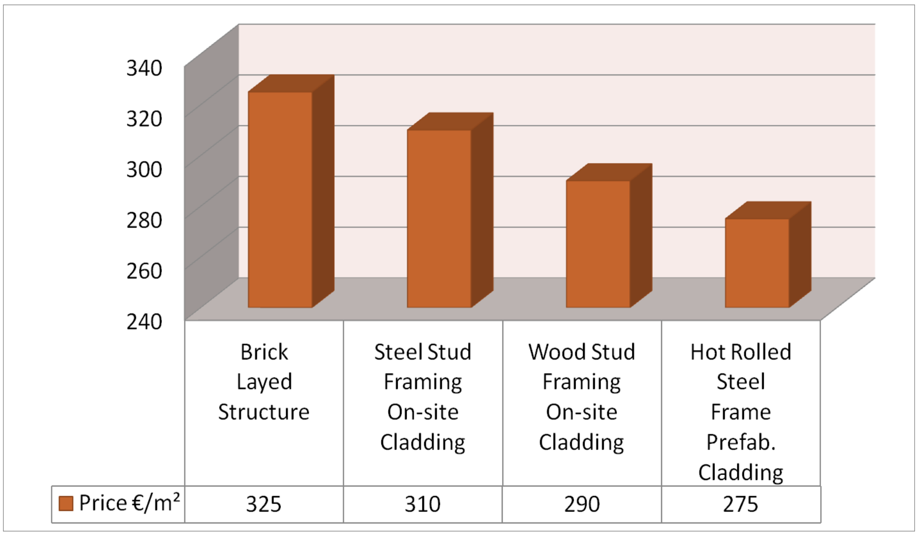
The company bases its market strategy on the fact that steel structure houses represent a very small segment on the construction market in Romania. "Romanian mentality constitutes the main hurdle while marketing this product", explains Marian Parvu, general manager at ArcelorMittal Construction.

ArcelorMittal Construction – Affordable Steel Frame Duplex House
"The selling price is 400 euro/m^2, without the price of land and utilities hook up."

Lindab

The company is currently promoting four types of houses, all of them built with cold formed light gauge steel profiles. The price is comparable with its competitor at around 400€/sqm.

Typical Lindab lightweight steel structure

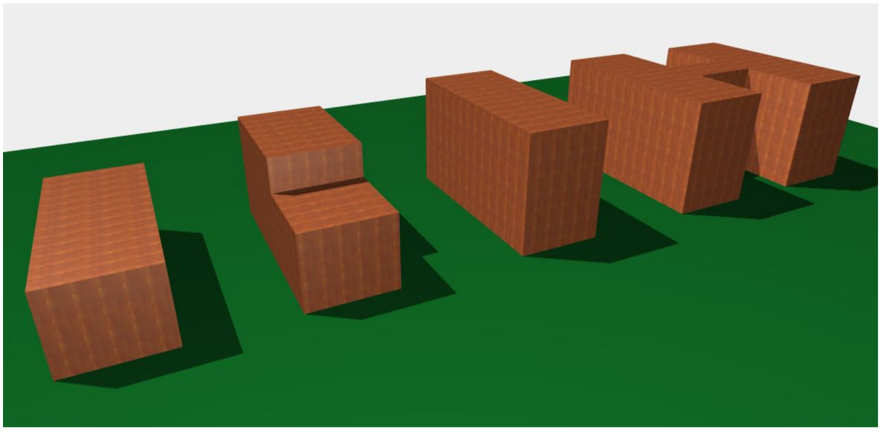


Comparative Construction Costs for the Proposed Design
Foundation, Structure, Envelope and Labor
60% of Total Construction Cost/ summer 2008

D.1.3.c. General description of the innovative process, solution, choices and related reasoning and justification.

The basic assumption behind the architectural concept is that a rectangular prism constitutes the logical volume to be fitted on a standard lot. By choosing a total building width of 5.60 m, and taking into consideration local urban planning regulations, the proposed houses could be built on lots as narrow as 9.50 m.

Starting from a basic footprint 5.60x13.40 m, the design proposes several possibilities of increasing the volume/usable area:



Modular progression of the typical one level unit.

1. house type 1: one level gross built area: 75.00 sqm
usable area: 61.95 sqm.

Steel consumption: 3240 kg

1. house type 1A: one level gross built area: 75.00 sqm
usable area: 61.95 sqm.

Steel consumption: 3900 kg

2. house type 2: gross built area: 119.60 sqm
usable area: 98.41 sqm.
3. house type 3: gross built area: 150.00 sqm
usable area: 124.41 sqm.
Steel consumption: 6200 kg

4. house type 4/twin houses: gross built area: 337.00 sqm
usable area: 248.82 sqm.

Estimated price is 400euro/sqm for a turn key project excepting the price of land and utilities.

The goal set by the design team is to further investigate, in phase WP2, how feasible such a modular growth pattern can be achieved technically, without hindering cost efficiency. For example, house type 1A is designed to support structurally another floor, at a later date, which might respond to evolving needs and increase the resale value. House type 2, can be obtained on the same principle.

If successful, we feel that such an approach, by fitting various budgets, can provide a more complete answer to market expectations, and help promote the product.

The proposed construction system consists of:

- hot rolled steel structure
- secondary structure - wood stud systems, combined with various envelope systems
- floor structure – light concrete topping on trapezoidal steel deck
- foundations and slab / cast in place reinforced concrete

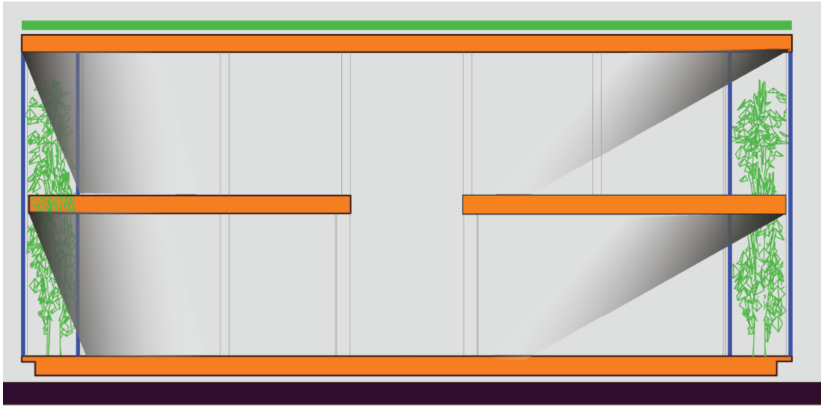
The roof terrace is planted with *sedums*, given the low maintenance factor and in order to reduce the thickness of the soil layer to max. 10 cm.

Achieving thermo energetic efficiency is another goal set by the design team. Several factors were taken into consideration:

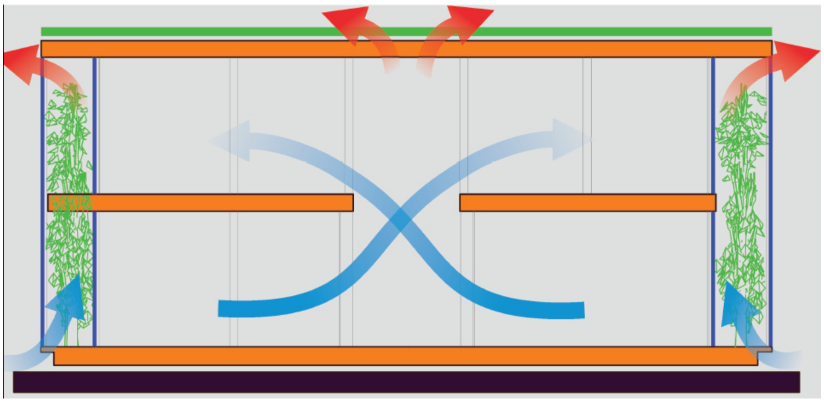
- Indoor temperature and air quality
- Thermal Insulation

Up values = 0.120 W/(mp*K) for roof
Up values = 0.180 W/(mp*K) for exterior wall

- Moisture Protection
- Different heating and cooling systems (conventional or unconventional – solar, heat pumps,)
- Passive ventilation and shading



Shading is achieved by the projection of the slabs onto the terraces.



Natural cross ventilation brings cooler air into the building.
The glazed terraces act as a buffer zone.

D.1.3.d. Advantages and disadvantages

Advantages

The most important advantage of the proposed design over the traditional building methods is structural safety. Steel structures are factory made and cannot be erected without proper site inspection, which is not the case for the traditional method. In a country with seismic risk, this design feature should make the difference. It is foreseeable that insurance companies in Romania, will display in the future more concern for the safety factor born out of structural design.

Steel main frame allows for:

- High design and construction safety standards
- Larger spans
- Layout flexibility
- Faster fabrication and erection times
- High solution diversity for flooring and envelope
- Easy to combine with timber

- Easy to combine with steel wall-studs, structural liner trays or insulated panels

Other advantages are:

- easy to build dry construction method;
- allows for a more accurate budget estimate and cost control;
- interior layouts can be modified;
- allows for a large variety of finishing;
- lower on-site labor cost;
- overall lower construction cost;
- sustainable design/ complete recycling of the steel frame and Q deck.
  - significant savings on the energy bill
  - eco roof – planted with *sedums*

Disadvantages

Requires more attention to build the foundations and lay out the anchor bolts.
Requires heavy equipment/ crane on site.
Requires better than average workmanship.
The house is not easy to sell given the local mentality.

D.1.3.e. Innovative aspects

The innovative aspect consists mainly in the application of industrial building technologies to a house project. The basic assumption is that an affordable house, instead of experimenting with materials which have no track record, should rely on standard technology, affordable to most of the builders.

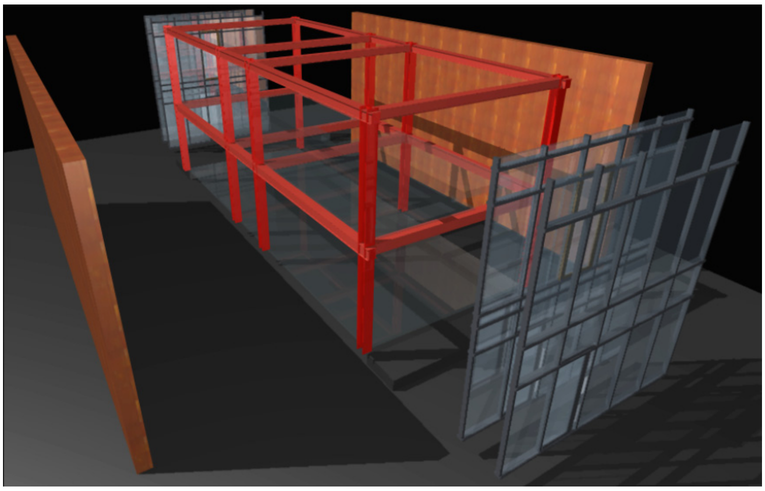
None of the technologies used, is new. On the contrary, such technologies are currently used on commercial projects allover the country.

The innovative aspect is the intention to apply such construction techniques to a residential application. Moreover, the proposed design tries to optimize the ratio between factory made components and site work. For this reason the enclosure structure is made of wood studs, as the material is significantly cheaper then steel studs, and does not require over qualified staff on site.

Our previous experience in designing and building steel stud framed houses, shows that understanding the project and realizing the assembly of components on site, can lead to significant losses of money and time.

Therefore, the design proposal is open to a situation in which, the steel frame, decks, etc., can be purchased (approved design package included) as a separate kit, by would to be owners who are in the position to undertake the construction for themselves.

In other words, we are attempting to “democratize” the access to technology.



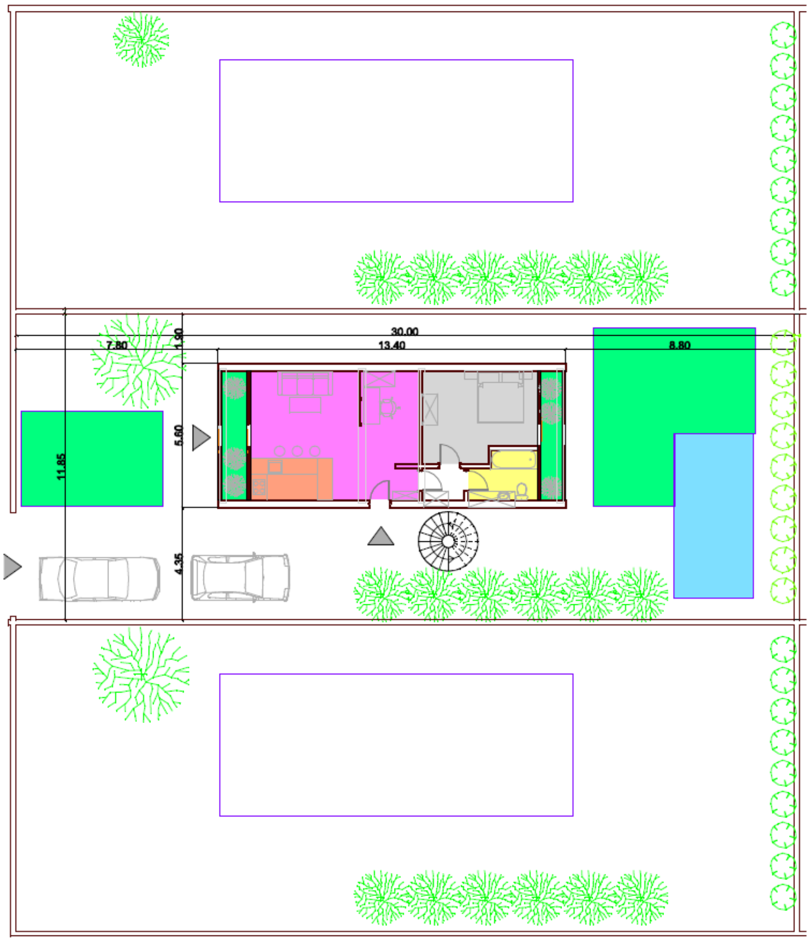
Schematic view of building components

D.1.3.f. Review of the selected technical solutions (if a decision has been made)

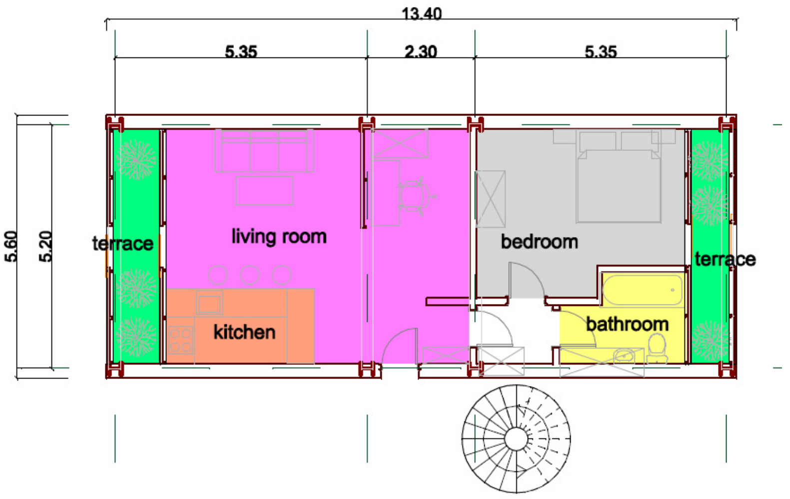
The overall design concept incorporates several building technologies currently used in Romania:

- cast in place reinforced concrete for foundations and slab;
- steel main frame structure;
- trapezoidal steel plates for floors and roof;
- wood stud secondary structure;
- double glazed loggias with PVC or aluminum frames.

D.1.3.g. Preliminary architectural project) plan of the floor/s or main floors, sections, views)



SUBDIVISION PROPOSAL
LOT SIZE = 30 x 11.85 m
LOT AREA = 355 sqm
HOUSE FOOTPRINT = 21.12%
COEFF. OF LOT UTIL. IN CASE HOUSE TYPE 1= 0.21
COEFF. OF LOT UTIL. IN CASE HOUSE TYPE 2 AND 3= 0.42



HOUSE TYPE 1

GROSS BUILT AREA : 75 sqm
USABLE AREA : 61.95 sqm

living room	=	27.1 sqm
kitchen	=	5.05 sqm
bedroom	=	14.5 sqm
bathroom	=	4.5 sqm
terraces	=	8.8 sqm
hallways	=	2.0 sqm
total	=	61.9 sqm

HOUSE TYPE 2

GROUND FLOOR GROSS BUILT AREA : 75.00 sqm
GROUND FLOOR USABLE AREA : 63.21 sqm
TOTAL GROSS BUILT AREA : 119.6 sqm
TOTAL USABLE AREA : 98.41 sqm

living room	=	19.4 sqm
dining room	=	4.51 sqm
kitchen	=	11.2 sqm
bathroom	=	2.35 sqm
terraces	=	10.1 sqm
hallways	=	15.7 sqm
total	=	63.2 sqm

HOUSE TYPE 2

UPPER FLOOR GROSS BUILT AREA : 44.6 sqm
UPPER FLOOR USABLE AREA : 35.21 sqm
TOTAL GROSS BUILT AREA : 119.6 sqm
TOTAL USABLE AREA : 98.41 sqm

bedroom	= 13.1 sqm
dressing	= 3.89 sqm
bathroom	= 4.68 sqm
terrace	= 4.1 sqm
hallways	= 9.44 sqm
outer terrace	= 26.1 sqm

HOUSE TYPE 3

GROUND FLOOR GROSS BUILT AREA : 75.00 sqm
GROUND FLOOR USABLE AREA : 63.21 sqm
TOTAL GROSS BUILT AREA : 150 sqm
TOTAL USABLE AREA : 124.41 sqm

living room	= 19.4 sqm
dining room	= 4.51 sqm
kitchen	= 11.2 sqm
bathroom	= 2.35 sqm
terraces	= 10.1 sqm
hallways	= 15.7 sqm
total	= 63.21 sqm

HOUSE TYPE 3

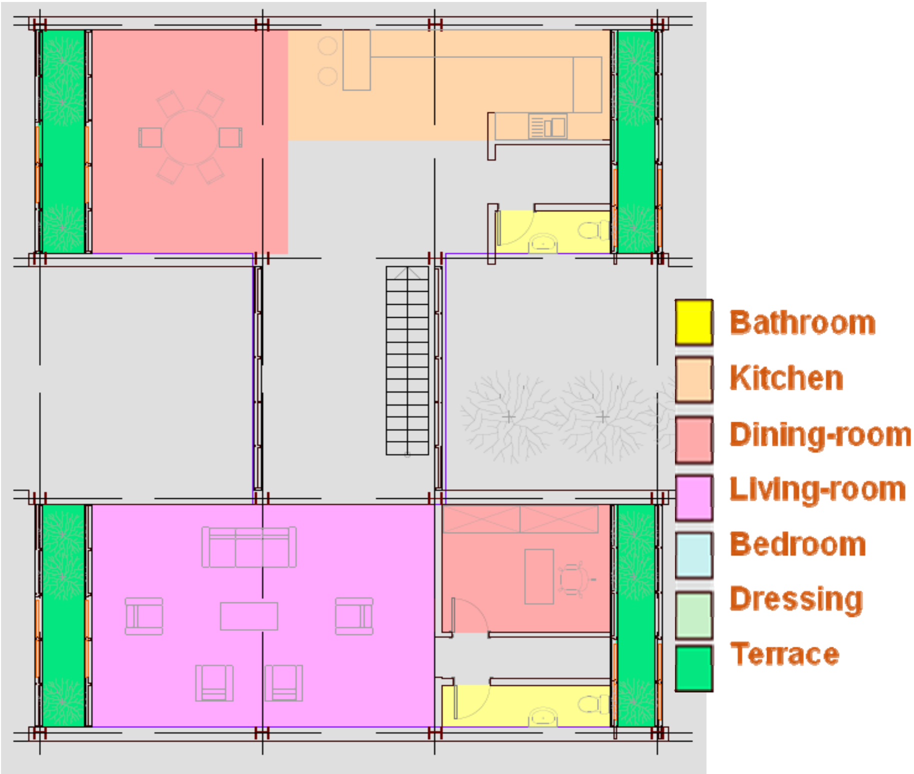
master bedroom	= 13.1 sqm
dressing	= 3.89 sqm
bathroom	= 4.68 sqm
bedroom	= 12.9 sqm
dressing	= 4.18 sqm
terraces	= 10.1 sqm
hallways	= 9.50 sqm
total	= 61.2 sqm

UPPER FLOOR GROSS BUILT AREA : 75.00 sqm

UPPER FLOOR USABLE AREA : 61.2 sqm

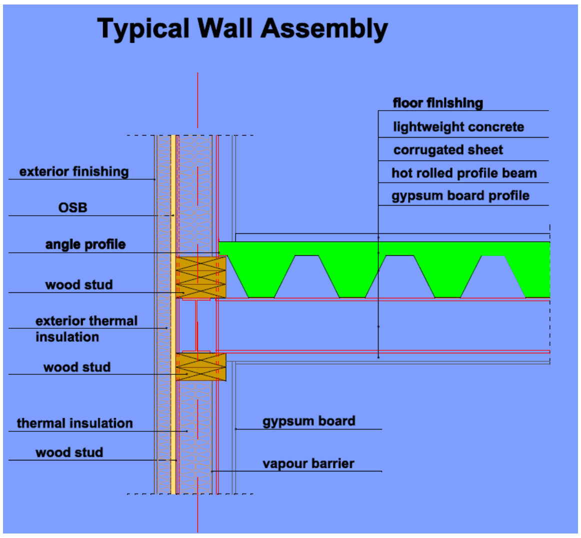
TOTAL GROSS BUILT AREA : 150 sqm

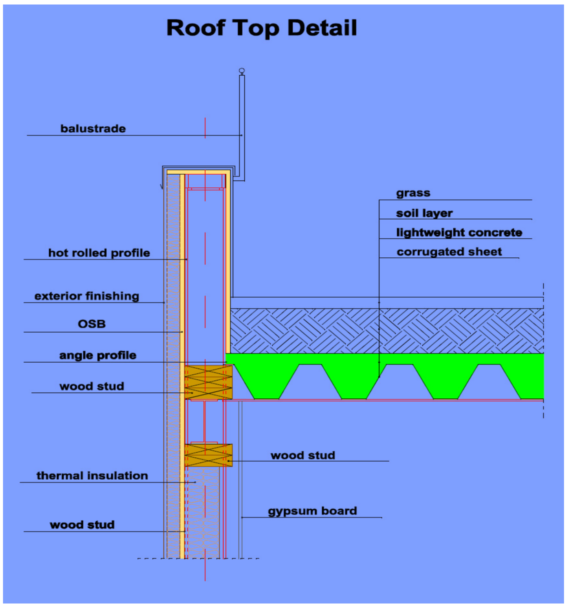
TOTAL USABLE AREA : 124.41 sqm

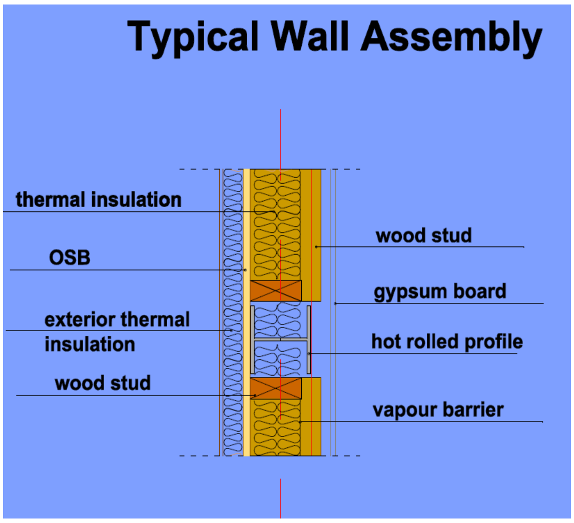


House Type 4
Ground Floor Plan
Gross built area: 337.00 sqm
Usable area: 248.82 sqm.

Second Level Plan


Typical Wall Assembly
floor finishing
lightweight concrete
corrugated sheet
hot rolled profile beam
gypsum board profile
exterior finishing
OSB
angle profile
wood stud
exterior thermal insulation
wood stud
thermal insulation
wood stud
gypsum board
vapour barrier


Roof Top Detail
balustrade
grass
soil layer
lightweight concrete
corrugated sheet
hot rolled profile
exterior finishing
OSB
angle profile
wood stud
wood stud
thermal insulation
gypsum board
wood stud



D.1.3.h. Preliminary structural project and design;

For all three cases the structures are made by transversal moment resisting frames, while on the longitudinal direction braced frames are used (see the next figures). All structures have fixed base connections using anchor bolts.

The foundation system uses the independent foundations and reinforced concrete slab cast in place.

The floors structure – dry system, are made by wide flange cold-formed trapezoidal sheeting of 153mm height and light concrete with a density of 600kg/m^3, prepared for large variety of finishing.

No secondary beams were used. The longitudinal cladding system is based on wood studs, combined with various envelope systems. In transversal direction double glazing facades are used to allow for cross ventilation.

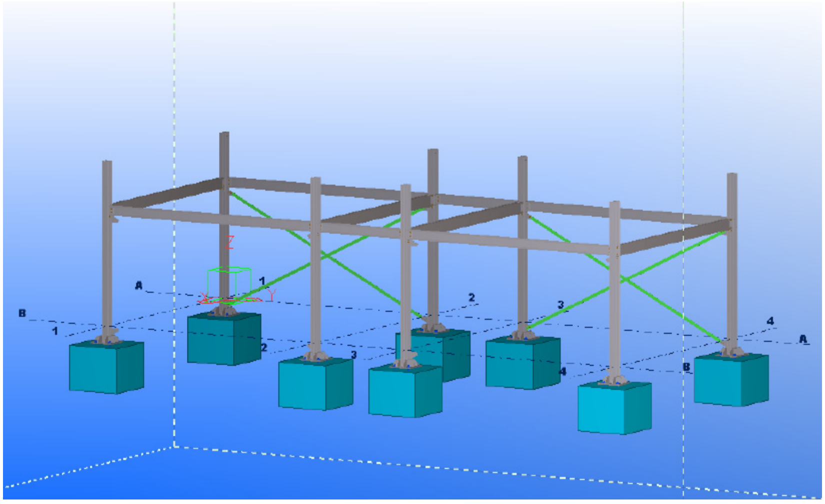
House Type 1: Single storey building

This structure is made of HEA160 columns, IPE 240 transversal beams and IPE 200 longitudinal beams. The steel consumption, including the anchor bolts is 3240kg.

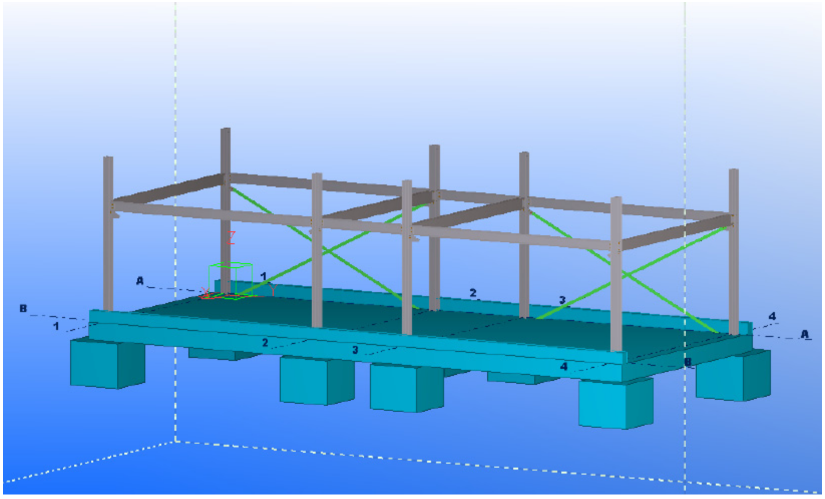
House Type 1A: Single storey building prepared to add an additional storey

This structure is made of HEA200 columns, IPE 240 transversal beams and IPE 220 longitudinal beams. The steel consumption, including the anchor bolts is 3900kg. This type of structure is prepared to extension by adding an additional story, similar with (3).

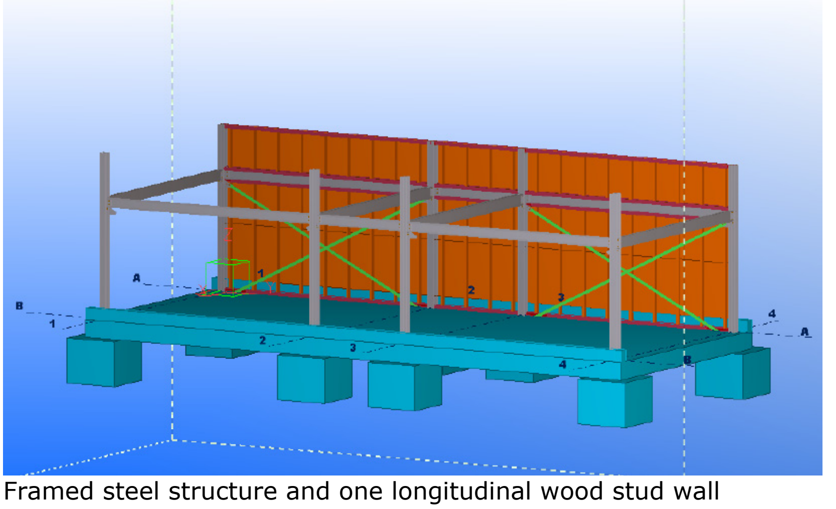
Schematic building model for **House Type 1 and 1A:**



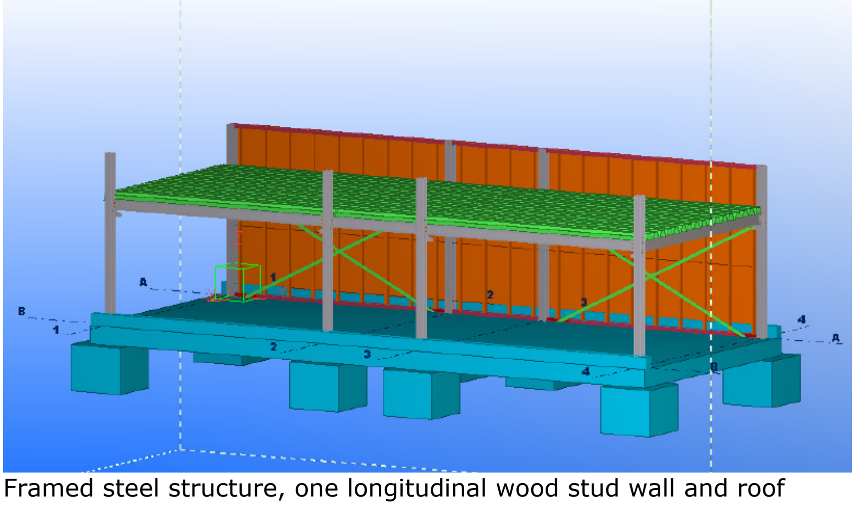
Framed steel structure and independent foundations



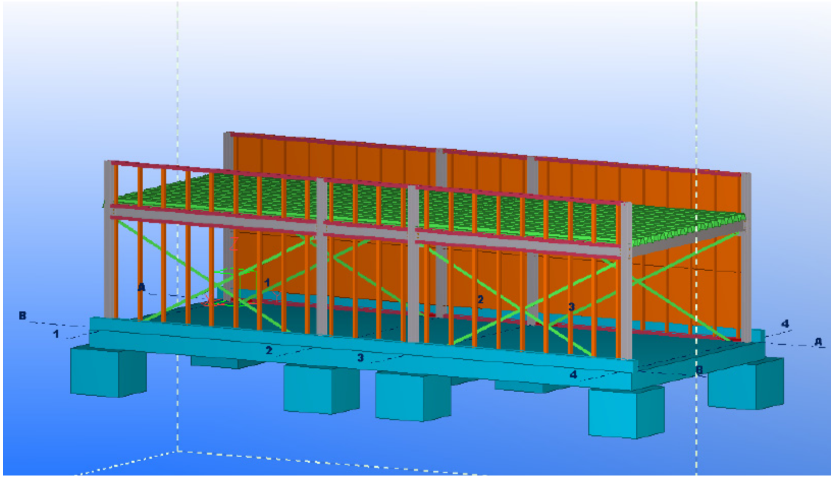
Framed steel structure, independent foundations and floor slab



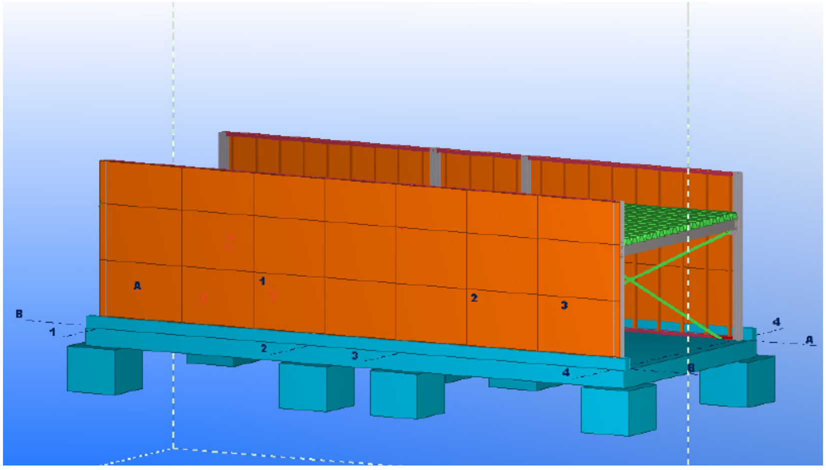
Framed steel structure and one longitudinal wood stud wall



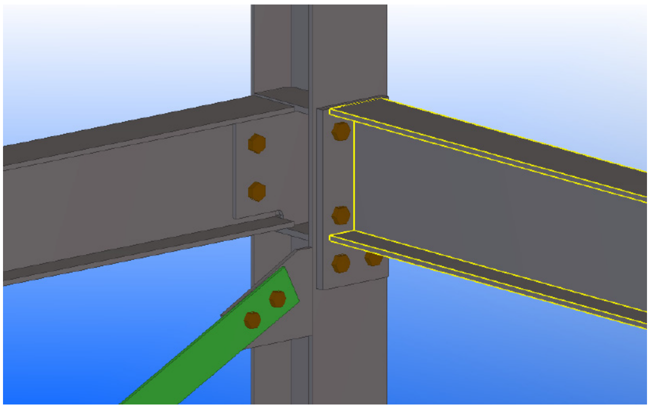
Framed steel structure, one longitudinal wood stud wall and roof



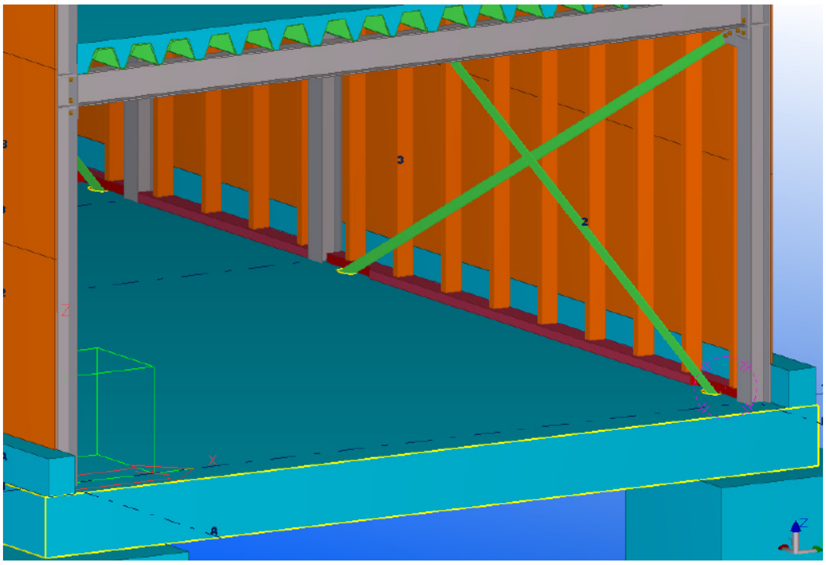
Complete framed enclosure wood stud walls



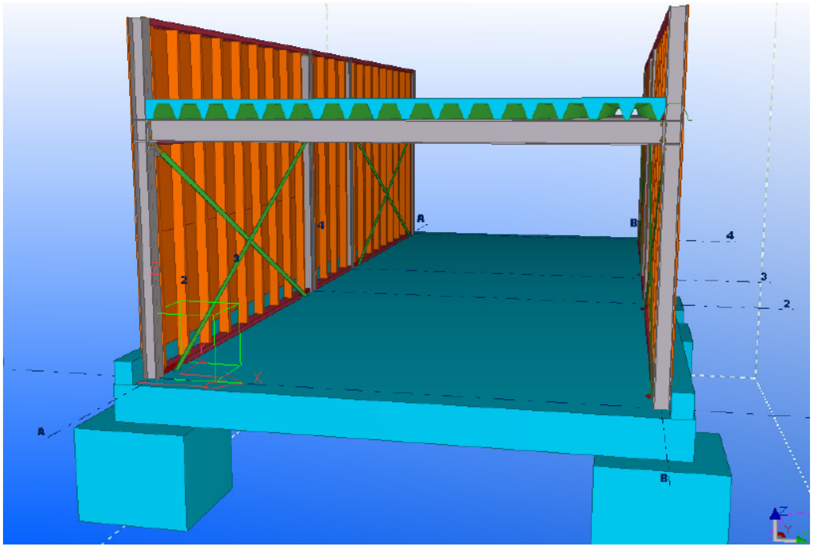
Complete enclosed unit



Typical joint



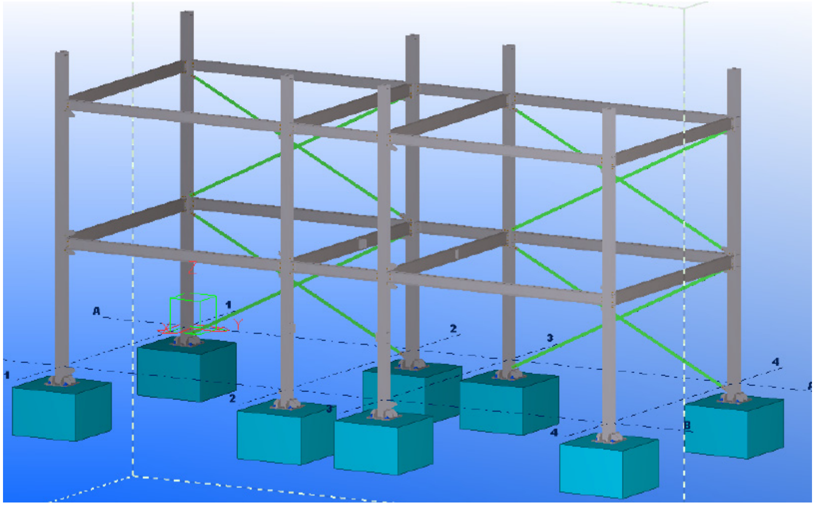
Typical transversal section



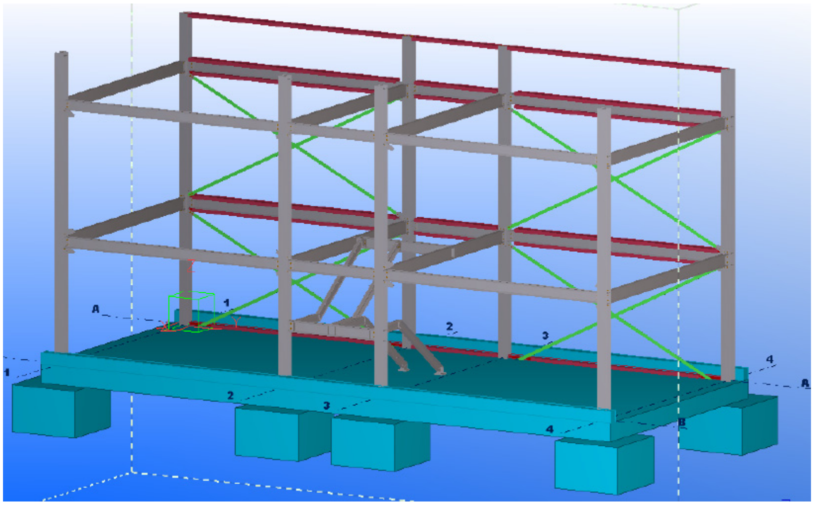
Typical transversal section

Schematic building model for **House Type 3:** Two storey building

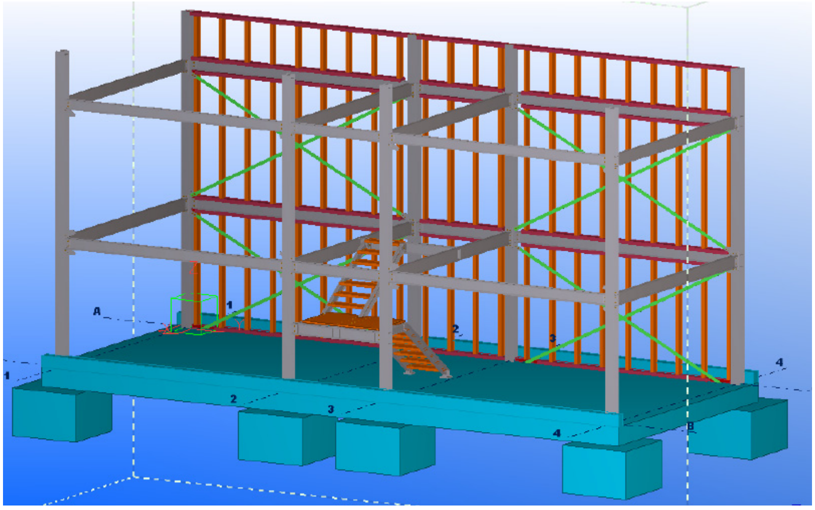
This structure is made of HEA200 columns. At the first floor IPE 240 transversal beams and IPE 220 longitudinal beams are used. At the level of roof IPE 220 transversal beams and IPE 200 longitudinal beams are used. The steel consumption, including the anchor bolts is 6200kg.



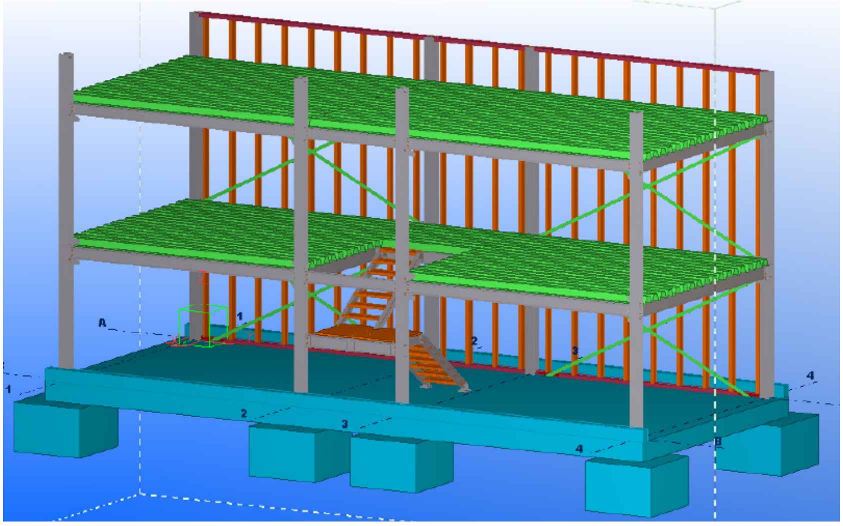
Framed steel structure and independent foundations



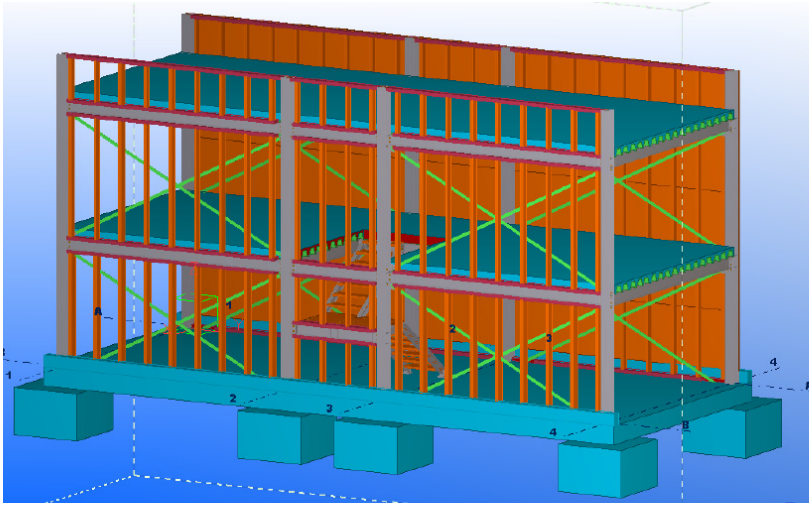
Framed steel structure, independent foundations and floor slab



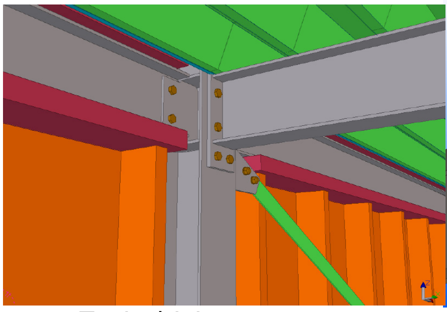
Framed steel structure and one longitudinal wood stud wall



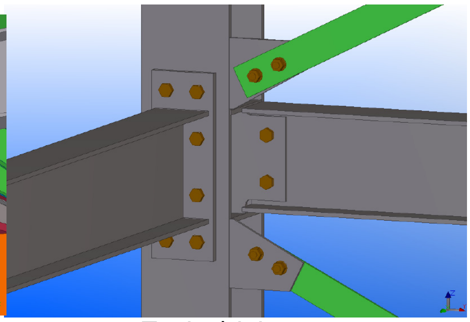
Framed steel structure, one longitudinal wood stud wall and floors



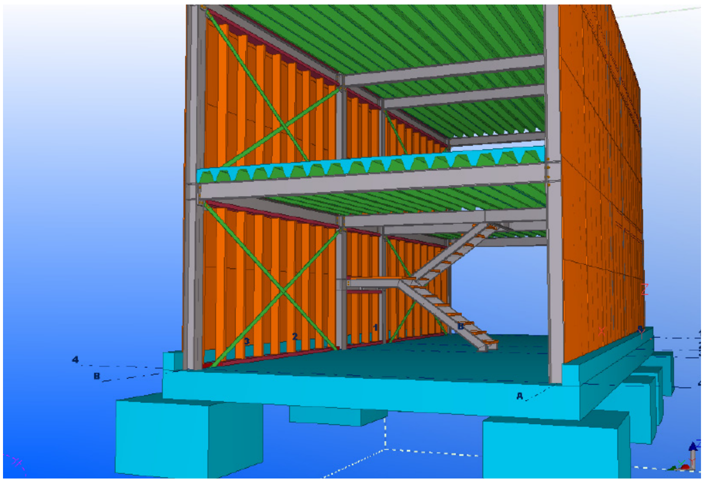
Complete framed enclosure wood stud walls



Typical joint



Typical joint



Typical transversal section

D.1.4. Follow up

D.1.4.a. General Planning

In planning work to be done in phase WP2, the design team will rely on the template and will incorporate any new ideas that might emerge from the workshop meeting.

D.1.4.b. Future activities planned within WP2

As explained above, we feel that to the next phase, the product can and should be refined. Basically, all chapters can be optimized in order to ensure an acceptable quality price ratio, within the set goal of 400euro/sqm construction price.

Programul PrimaCasa

"The First Home" housing development program, is going to produce effects soon, so any relevant data will be duly analyzed. For now, we are attempting to make the best use of the 57,000 € a first time would to be owner is able to get as a bank loan, state guaranteed.

The 1 bln € allocated for this program this year, can cover in bank guarantees more than 16,500 first homes, would they be apartment or houses.

The general assumption is that the first to go will be the unfinished apartments belonging to residential projects which were interrupted by the economic crisis. This has to be yet decided by the buyers and at the present time, no one can guarantee what the potential owners have in mind.

The future activities the design team is planning to undertake within WP2 will be responding to all signals coming from the market.

Another very important design chapter to be tackled in phase WP2, are the interior finishing. Even though "interior design" might prove to be to strong of a word when discussing affordable housing, the fact of the matter is that a well packaged product will always sell better.

In order to carry the concept to the dimension of a subdivision, we are planning to make some mock-ups of portions of a subdivision, streets, populated with the four types of houses presented above, for which we will device various facades.

D.1.4.c. Critical points and risk analysis

Assuming that all technical issues will be satisfactorily solved during WP2, we foresee at the present, two areas which in our view, might prove critical to the implementation of the project.

The first is the struggle to achieve a reasonable, acceptable price/quality ratio.

The second is to design/package the product in such a way that it becomes desirable for the targeted segment of clientele.

These two aspects inter-relate, as budget components can and should be dimensioned from the beginning, in order to reach a planned effect upon the targeted segment of clientele.

It is quite obvious that the marketing strategy within the business plan will have to play a very important role in the successful launching of the product on the market.

Annex 2

Université de Liège

ArcelorMittal

AFFORDABLE HOUSES PROJECT

FINAL PROJECT AND DESIGN – WP2

Submitted by:

Prof. Dan Dubină, PhD, C.Eng.
Mihai Muţiu, Arch., O.A.R.
Assoc. Prof. Viorel Ungureanu, PhD, C.Eng.
The "Politehnica" University of Timişoara, Romania

Table of Contents

D2.1: Final design and detailed description of the technical solutions

D2.1.a. General description

The goal set for the project is to develop a design solution easy to build in the context of the Romanian construction sector, with a modular progression, faster fabrication and erection times, with an adaptable layout and a variety of enclosure solutions. The design solution can be adapted to maximize the steel component or to incorporate more wood and wood by-products.

The architectural concept relies on the development of a rectangular footprint of 5.60 x 13.40 m, which gives a first module of 75 sqm, for the one level unit.

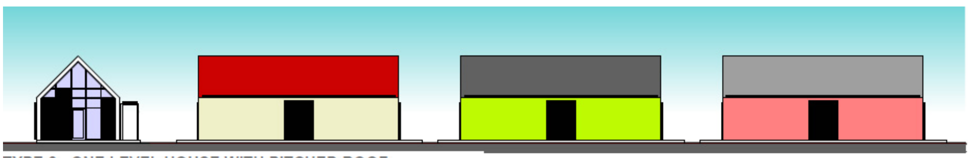
Urban planning regulations allowing in residential areas for a 30% land occupancy ratio, means that a 75 sqm. built area could fit on a minimum 250 sqm. lot. In terms of architectural form, both a modern terraced roof and a traditional pitched roof can be considered. This way, the architectural expression can be easier adapted to different sites and marketing strategies.

The modular progression is described below:

House type 1: gross built area: 75 sqm.
One level, terraced roof usable area: 61.95 sqm.

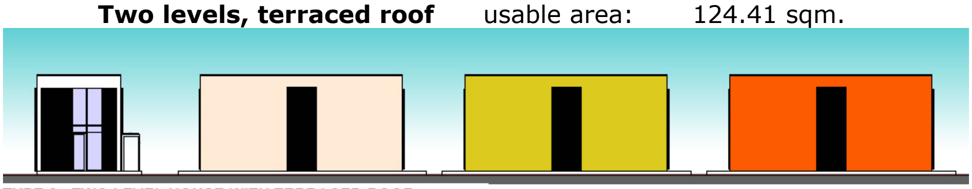
TYPE 1 - ONE LEVEL HOUSE WITH TERRACED ROOF

House type 2: gross built area: 75 sqm.
One level, pitched roof usable area: 61.95 sqm.



TYPE 2 - ONE LEVEL HOUSE WITH PITCHED ROOF

House type 3: gross built area: 150 sqm.
Two levels, terraced roof usable area: 124.41 sqm.



TYPE 3 - TWO LEVEL HOUSE WITH TERRACED ROOF

Detailed in the project

House type 4: gross built area: 150 sqm.
Two levels, pitched roof usable area:
124.41 sqm.

TYPE 4 - TWO LEVEL HOUSE WITH PITCHED ROOF

However, two single units can be combined to obtain a duplex configuration:

House type 5A/twin houses: gross built area: 337 sqm.
Two levels, terraced roof usable area: 248.82 sqm.

House type 5B/twin houses: gross built area: 337 sqm.
Two levels, pitched roof usable area:
248.82 sqm.

Figure 1 and Figure 2 below illustrate the proposed progression from the basic footprint 5.60x13.40m.

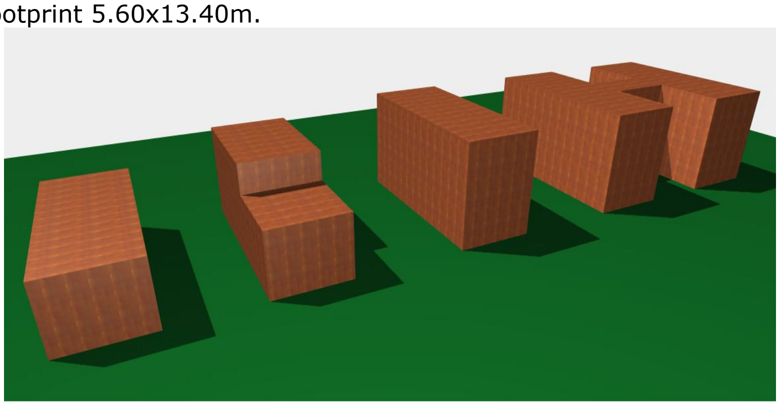


Fig. 1: Modular progression of the typical one level unit/terraced roof construction

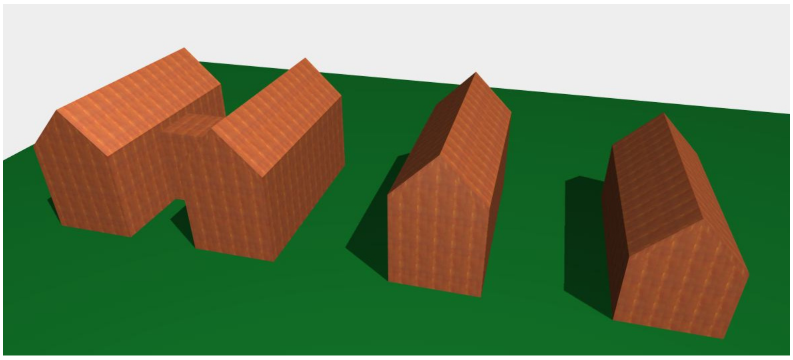


Fig. 2: Modular progression of the typical one level unit/pitched roof construction

In the present project house type 3 is detailed. Final documentation is provided for this type only.

However, it has to be underlined, as previously specified in WP1 deliverables, a two storey solution can be easily adapted for a modular construction as follows:

Phase 1: house type 1 can be designed and erected to support structurally another floor.

Phase 2: at a later date which might respond to evolving needs and increase the resale value, a new floor to be installed leading to house type 3 or 4.

We feel that such a phased approach could help the financing aspect and help to promote the product.

The proposed construction system consists of (see Figure 3):

- hot-rolled framed steel structure;
- secondary structure - wood stud systems, combined with various envelope systems;
- alternatively, the secondary structure can be made out of steel studs;
- floor structure – light concrete topping on trapezoidal steel deck;
- double glazed loggias with PVC or aluminium frames;
- foundations and slab / cast in place reinforced concrete.

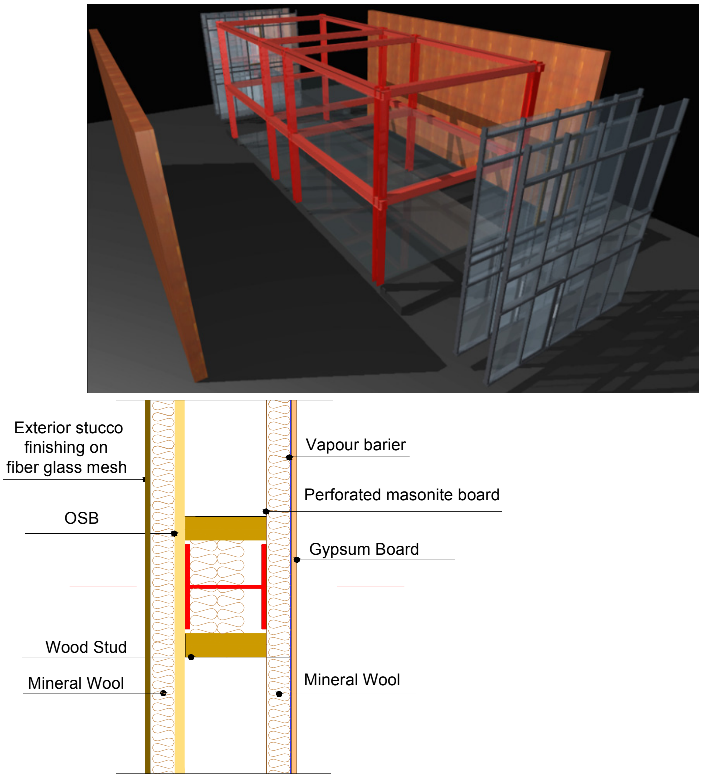


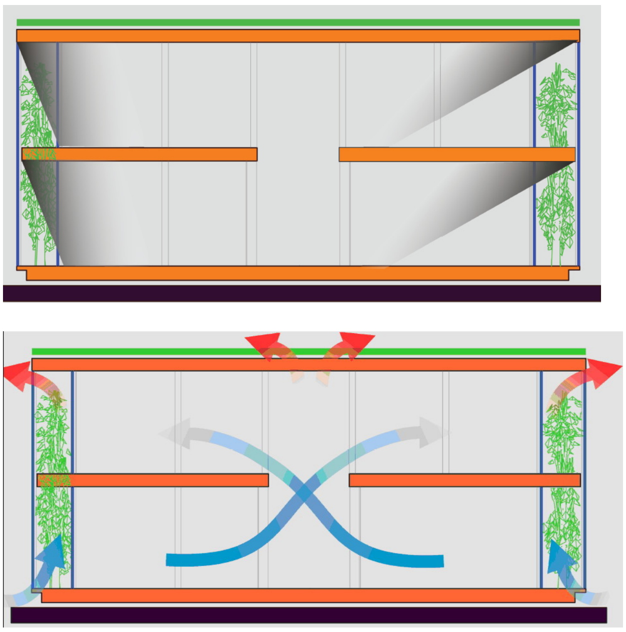
Fig. 3: Schematic view of building components and typical wall assembly

The roof terrace is planted with *sedums*, given the low maintenance factor and in order to reduce the thickness of the soil layer to max. 4 cm.

Achieving thermo energetic efficiency is another goal set by the design team. Several factors were taken into consideration:

- Indoor temperature and air quality;
- Thermal insulation:
  Up values = 0.289 W/(m^2*K) for roof
  Up values = 0.297 W/(m^2*K) for exterior wall;
- Moisture protection;
- Different heating and cooling systems (conventional or unconventional – solar, heat pumps);
- Passive ventilation and shading;
- The glazed loggias act as a buffer zone;
- Ventilation of the loggias is achieved between the floors through openings in the floor;
- Shading is achieved by the projection of the slabs onto the terraces;
- Natural cross ventilation brings cooler air into the building.

The presented solution allows for a large variety of finishing, sustainable design, lower onsite labour cost and overall lower construction costs.



(a) (b)

Fig. 4: (a) Shading is achieved by the projection of the slabs onto the loggias. (b) Natural cross ventilation brings cooler air into the building.

D2.1.b. Innovative aspects

The innovative aspect consists mainly in the application of industrial building technologies to a house project (residential application). The basic assumption is that an affordable house, instead of experimenting with materials which have no track record, should rely on standard technology, affordable to most of the builders. None of the technologies used, is new. On the contrary, such technologies are currently used on commercial projects all over the country.

The innovative aspect consists in the application of such construction techniques to a residential project. Moreover, the proposed design tries to optimize the ratio between factory made components and site work. For this reason the enclosure structure is made of wood studs, as the material is significantly cheaper then steel studs, and does not require over qualified staff on site.

Our previous experience in designing and building steel stud framed houses shows that understanding the project and realizing the assembly of components on site, without the benefit of a trained work force, can lead to significant losses of money and time.

Therefore, the design proposal is open to a situation in which, the steel frame, decks, etc., can be purchased (approved design package included) as a separate kit and assembled by a certified builder, while the cladding system and finishing could be undertaken by the owners themselves, acting as contractors. In this respect the *Habitat for Humanity* action in Romania is relevant.

Current building technologies are used in order to implement the proposed (and innovative!) concept, i.e.:

- cast in place reinforced concrete for foundations and slab;
- steel main frame structure;
- trapezoidal steel plates for floors and roof;
- wood stud secondary structure (alternatively cold-formed steel studs could be used);
- double glazed loggias with PVC or aluminium frames.

D.2.1.c. Advantage, disadvantage, feasibility study

Advantages

The most important advantage of the proposed design over the traditional building methods is structural safety. Steel structures are factory made and cannot be erected without proper site inspection, which is not the case for the traditional method. In a country with seismic risk, this design feature should make the difference. It is foreseeable that insurance companies in Romania will display in the future more concern for the safety factor born out of structural design.

Steel main frame allows for:

- High design and construction safety and quality standards;
- Larger spans;
- Layout flexibility;
- Faster fabrication and erection;
- Large solution diversity for flooring and envelope;
- Easy to combine with timber;
- Easy to combine with steel wall-studs, structural liner trays or insulated panels;

- Thermo efficiency of cladding system (for roof = 0.289 W/(m^2*K); for exterior wall = 0.297 W/(m^2*K)). It has to be underlined that the air layer for double glazing plays the role of a thermal barrier.

Other advantages are:
- Easy to apply dry construction technologies;
- Allows for a more accurate estimation of budget and cost control;
- Interior layouts can be modified;
- Allows for a large variety of finishing;
- Lower on-site cost;
- Overall lower construction cost;
- Sustainable design / complete recycling of the steel frame structure and trapezoidal corrugated steel sheet for floor decks;
- Significant savings on the energy bill (minimum required values according to Romanian C107-2005 code: for roof = 3(m^2*K)/W; for exterior wall = 1.4(m^2*K)/W);
- Eco roof.

Disadvantages

- Requires more precision to build the foundations and lay out the anchor bolts;
- Requires for crane on site during the main frame erection;
- To sell a steel framing house calls for appropriate advertising and lobbying in order to overcome traditional mentality (*"stone house"!*).

D.2.1.d. Final architectural project (plans, sections, views, rendering/mock-up)

Architectural drawing list

A01 Ground floor plan, furniture layout	Scale 1:50
A02 Upper floor plan, furniture layout	Scale 1:50
A03 Ground floor plan	Scale 1:50
A04 Upper floor plan	Scale 1:50
A05 Terraced roof plan	Scale 1:50
A06 Cross section	Scale 1:50
A07 Longitudinal section	Scale 1:50
A08 Front elevation	Scale 1:50
A09 Rear elevation	Scale 1:50
A10 Lateral elevation with entry	Scale 1:50
A11 Lateral elevation	Scale 1:50
A12 Interior doors and glazed walls schedule	Scale 1:50
A13 Details	Scale 1:20
A14 Details	Scale 1:20
A15 Details	Scale 1:20
A16 Architectural renderings Type 1	
A17 Architectural renderings Type 2	
A18 Architectural renderings Type 3	
A19 Architectural renderings Type 4	
A20 Colour Palette	
A21 Architectural renderings	

A22 Architectural renderings
A23 Architectural renderings

For complete working drawings see attached folder D.2.1.d-drawings.

D.2.1.e. Detailed structural design

1. Technical background

1.1 Main characteristics of the structure

The structure is a two-storey single family house, having the characteristic dimensions presented in Table 1. Figure 5 present the 3D structural view.

Table 1 – Geometrical characteristics

Span:	5.2 m
Bays:	5.35 m; 2.3 m; 5.35 m
Total length:	13 m
Number of bays:	3
Eaves level:	+5.82 m
Attic level :	+6.37 m
Roof type:	terrace

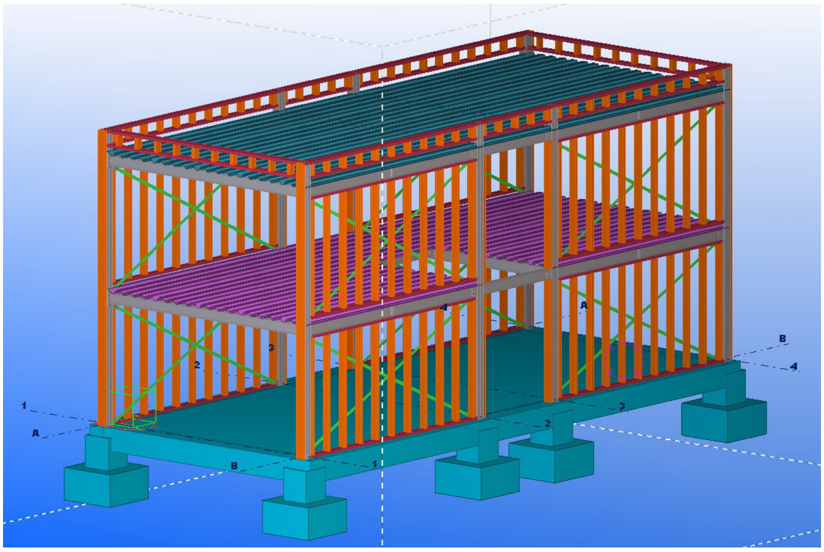


Fig. 5: 3D view of the house

1.2 Loads evaluation

The loads used for the design of the structure are taken according to Romanian codes, actually aligned to relevant Eurocodes, i.e.:

- Dead loads (according with architectural details and EN1991-1-1);
- Snow loads (EN1991-1-3 and CR1-1-3-2005);

- Wind loads (EN1991-1-4 and NP-082-04);
- Imposed loads (EN1991-1-1);
- Seismic loads (P100-1/2006).

Combinations of actions were done in accordance with EN1990:2002.

1.2.1 Permanent action

Characteristic values of permanent loads considered in design (according with architectural details and EN1991-1-1) are:

- *the weight of the steel structural skeleton*;
- *dead load of the intermediate slab* (parquet finishing): g^n=1.65 kN/m^2

parquet	8 kg/m^2
cork	10.5 kg/m^2
corrugated sheet	13.7 kg/m^2
lightweight concrete (ρ=600kg/m^3)	67.8 kg/m^2
gypsum board	40 kg/m^2
partition walls	25 kg/m^2

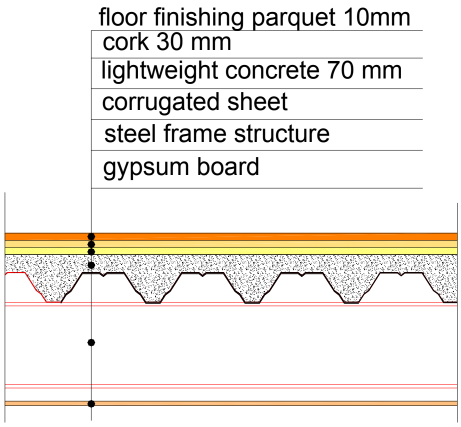


Fig. 6. Layers of the slab between floors (Parquet finishing)

- *dead load of the intermediate slab* (cold flooring): g^n=1.93kN/m^2

ceramic tiles finishing	23.6 kg/m^2
lightweight concrete (ρ=600kg/m^3)	30 kg/m^2
waterproofing membrane	5 kg/m^2
corrugated sheet	13.7 kg/m^2
lightweight concrete	55.8 kg/m^2
gypsum board	40 kg/m^2
partition walls	25 kg/m^2

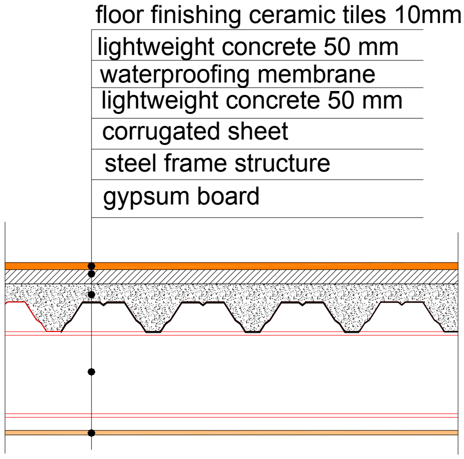


Fig. 7. Layers of the slab between floors (cold finishing)

- *dead load on the roof:* g^n=1.45kN/m²

soil	72 kg/m²
bituminous membrane	7 kg/m²
thermal insulation (foam glass)	15 kg/m²
corrugated steel sheet	10.6 kg/m²
gypsum board	40 kg/m²

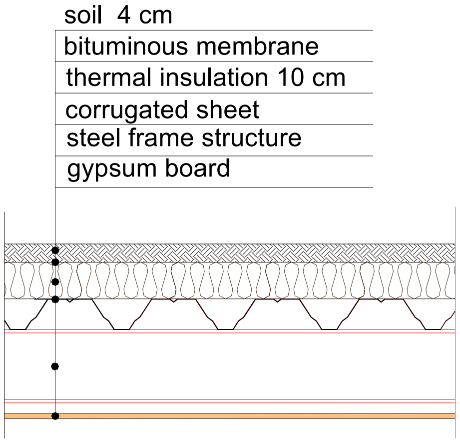


Fig. 8. Layers of the roof slab

- *weight of the walls:* g^n=0.77 kN/m²

mineral plastering	4.5 kg/m²
thermal insulation	4 kg/m²
OSB	14 kg/m²
mineral wool	8 kg/m²

gypsum board 11 kg/m^2
wood skeleton 20 kg/m^2
gypsum board skeleton 15 kg/m^2
vapour barrier weight negligible
perforated masonite board weight negligible

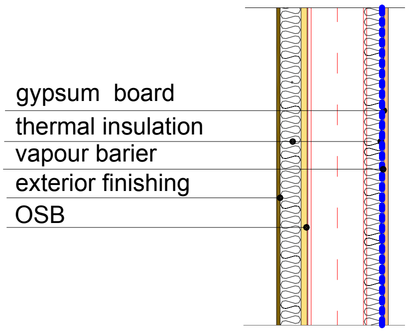


Fig. 9. External wall layers

- *weight of the glass wall:* g^n=0.45 kN/m^2

1.2.2 Imposed load

According to EN1991-1-1: Eurocode 1, Part 1.1 – Actions on structures, the building is of Category A (Areas for domestic and residential activities), so the live loads are:
- floors: q_n = 2 KN/m^2;
- stairs: q_n = 3 KN/m^2.

1.2.3 Snow load

According to EN1991-1-3 and CR1-1-3-2005, the snow load on the roof is:
$S_k = \mu_i\ C_e\ C_t\ s_{0,k} = 1.2$ kN/m^2
where:
μ_i – snow load shape coefficient (acc. to Table. 3.1 and figure 3.3/ CR 1-1-3-2005, μ_1=0.8);
$s_{0,k}$ – characteristic value of snow [kN/m^2] on the ground at the relevant site (for Timisoara, $s_{0,k}$ = 1.5 kN/m^2);
C_e – exposure coefficient (C_e = 1 according to Table 2.1/ CR 1-1-3-2005);
C_t – thermal coefficient (C_t = 1).

1.2.4. Wind load

According to EN1991-1-4 and NP-082-04, the wind load is:
$W(z) = q_{ref} \times C_e \times (z) \times C_p$
where:
$C_e(z)$ = exposure factor at height z above the ground
$C_e(z) = cg(z) \times cr(z) = 1.425$ (graph 5, paragraph 11)
$C_g(z) = 1+1.35[2I(z)] = 3.153$
$I(z)=\beta^{0.5}/2.5\ln(z/z_0) = 0.308$

$C_r(z) = k_r^2(z_0)\ (\ln z/z_0)^2 = 0.452$

q_{ref} = reference wind pressure for Timisoara= 0.4 kPa (acc. to Annexe A/ NP-082-04)

c_p – pressure coefficient ($c_{pe,10}$ acc. to chapter 12 from NP-082-04).

1.2.5 Seismic action

Seismic action is evaluated in accordance with the Romanian code P100-1/2006. For Timisoara, the peak ground acceleration is a_g*=0.16g* and the corner period at the upper limit of the constant acceleration region of the elastic spectrum is *Tc=0.7s.* Elastic response spectra for horizontal components of terrain acceleration, □*(T),* for the fraction of critical dumping □ *=0,05* and the corner period *Tc=0.7s* is presented in Figure 10. The structure is considered as non dissipative ⇒ q=1; this means that during the earthquake the structure remains in elastic range.

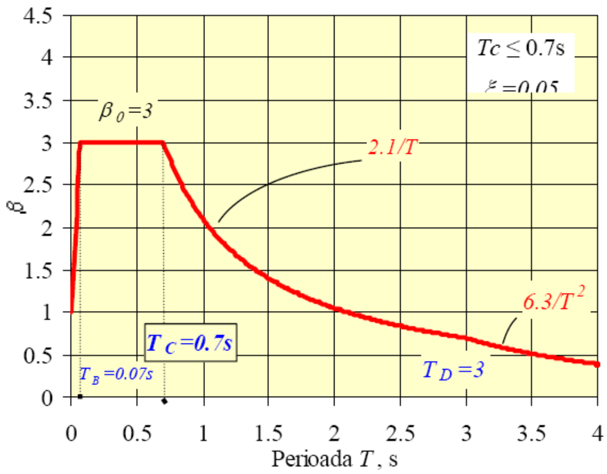


Fig. 10. Elastic response spectra for horizontal components of terrain acceleration, □*(T)*

Finally it should be mention that Romania covers a wide range of climatic, geotechnical and seismic conditions. These values are summarised in the table below. The values corresponding for Timisoara covers more than 60% from Romanian territory. For the remaining 40% of Romanian territory adjustment of the existing project should be done.

Natural Conditions	Snow Load [KN/m²]	Wind Pressure [KN/m²]	Frost Depth [m]	Ground Acceleration Seismic Load
Interval Values Romania	1.5 – 2.5	0.4 – 0.7	0.6 – 1.1	0.08g – 0.32g
Timisoara	1.5	0.4	0.7	0.16g

1.3. Combinations of actions

Combinations of actions were done in accordance with EN1990:2002. For static analysis, the following loads were taken into account:

P	Dead Load
Z	Snow load
V.T.	Transversal wind load
V.L.	Longitudinal Wind load
U	Live load
S	Seismic load

The following combinations were used:

A) Fundamental combinations

Ultimate limit state

The combination of the structural effects of the loads, for the ULS checking of the structure was made using the relation:

$$1.35\sum_{j=1}^{n} G_{k,j} + 1.5Q_{k,1} + \sum_{i=2}^{m} Q_{k,i}$$

where:

- $G_{k,j}$ = Characteristic value of the permanent action j;
- $Q_{k,i}$ = Characteristic value of the accompanying variable action i;
- $Q_{k,1}$ = Characteristic value of the leading variable action 1;
- $\psi_{0,i}$ = Factor for combination value of the variable action i, taken with the characteristic value (0.70 for the actions considered).

For static and dynamic analysis, the following combinations were used:

Comb.1	1.35 P+	1.5 U		
Comb.2	1.35 P+	1.5 Z		
Comb.3	1.35 P+	1.5 V.T.		
Comb.4	1.35 P+	1.5 V.L.		
Comb.5	1.35 P+	1.5 U+	1.05 Z	
Comb.6	1.35 P+	1.5 U+	1.05 VT	
Comb.7	1.35 P+	1.5 U+	1.05 VL	
Comb.8	1.35 P+	1.5 Z+	1.05 U	
Comb.9	1.35 P+	1.5 Z+	1.05 VT	

Comb.10	1. 35 P+	1.5 Z+	1.05 VL	
Comb.11	1. 35 P+	1.5 VT+	1.05 U	
Comb.12	1. 35 P+	1.5 VT+	1.05 Z	
Comb.13	1. 35 P+	1.5 VL+	1.05 U	
Comb.14	1. 35 P+	1.5 VL+	1.05 Z	
Comb.15	1. 35 P+	1.5 U+	1.05 Z+	1.05 VT
Comb.16	1. 35 P+	1.5 U+	1.05 Z+	1.05 VL
Comb.17	1. 35 P+	1.5 Z+	1.05 U+	1.05 VT
Comb.18	1. 35 P+	1.5 Z+	1.05 U+	1.05 VL
Comb.19	1. 35 P+	1.5 VT+	1.05 U+	1.05 Z
Comb.20	1. 35 P+	1.5 VL+	1.05 U+	1.05 Z

Serviceability limit state:

$$\sum_{j=1}^{n} G_{k,j} + Q_{k,1} + \sum_{i=2}^{m} \psi_{0,i} Q_{k,i}$$

The combinations of loads are the same as for ULS, taking into account the coefficients from the above relation.

B) Special combination

$$\sum_{j=1}^{n} G_{k,j} + \gamma_I A_{E,k} + \sum_{i=2}^{m} \psi_{2,i} Q_{k,i}$$

where:

- $A_{E,k}$ = Characteristic value of seismic action
- $\psi_{0,i}$ = Factor for combination value of the variable action i
- Q_i = 0.4 for snow load and live load

For static and dynamic analysis, the following combination was used:

Comb.21 1.0P + 0.4U + 0.4Z + S for ULS

Comb.22 1.0P + 0.4U + 0.4Z + 0.5S for SLS

1.4 Structural design

The steel structure is a multi-storey rigid portal frames structure on transversal direction, while on longitudinal one is a braced frame. Columns are made by hot-rolled profiles and are rigid at the base on transversal direction and pinned on longitudinal direction. The transversal girders are made by hot-rolled profiles and are semi-rigid at both ends while the longitudinal girders, which stabilize the transversal frames, are pinned on the columns. To take over the horizontal loads vertical bracings are disposed. Main structural skeleton is made by hot-rolled profile (European profiles HEA for columns, IPE profiles for beams).

The static and dynamic analysis was performed using Axis VM 9.0 software. The design of the structural elements (columns, beams, bracings) was made according with EN1993-1-1, EN1993-1-3, EN1993-1-8 and Romanian seismic design code P100-1/2006, both for Ultimate limit state and Serviceability limit state. To control the floor vibrations the limit to avoid significant discomfort to users was taken L/350, reasonable value for a family house.

Main structural skeleton is made by hot-rolled profile. The materials used are as follows:

- S355J0 steel for beams;
- S355J0 steel for columns;
- M16 gr.10.9 bolts for beam-column connection;
- M16 gr.10.9 bolts for bracings connection;
- M30 gr. 6.6. anchorage bolts.

1.5 Foundations

The foundations have been designed for a current soil in Timisoara area, i.e.:

The foundation soil has the following stratification:

- 0.00 – 0.30 m = vegetal soil γ =16.7 KN/m^3
- 0.30 – 7.5 m = sandy dust:
  γ = 18.8 KN/m^3 e = 0.65 Sr = 0.8
  Ic = 0.8 Ø = 190 c = 14 KN/m^2
  E = 10000 KN/m^2
- 7,5 m – ….. = sandy clay
  γ = 21 KN/m^3 e = 0.74
  Ic = 0.78 Ø = 240 c = 12 KN/m^2
  E= 22000 KN/m^2

The underground water level is H= 6.00 m.
The frost depth for Timisoara is H_i= 70 cm (Acc. to STAS 6054/77).

According to NP112-04 §3.2.4. Table 3.1
For sandy silt having $H_i \leq 0.70$m and H>2.50m, the foundation depth must me greater than 80 cm (H_f > 80 cm).

According to NP112-04 §6.1.5
- The building category = common building (CO)
- Sensitivity to the differentiated settlements = not sensitive

- Restrains regarding the serviceability deformations = no restrains

According to NP112-04 §6.1.6, the foundation design differ function of the soil category:

- good soils (TB)
- difficult soils

According to NP112-04, table 6.1, for cohesive soils with medium plasticity (sandy silt), having e<1 and $I_c \geq 0.5$, the foundation soil will be considered a good one (TB).

According to NP112-04, table 6.2, for good foundation soils (TB), building's importance class regular building (CO), soil not sensitive to the differentiated settlements and without restrains regarding the serviceability deformations, the design of the foundation will be made by considering the conventional pressure p_{conv}, as the acceptable pressure. Isolated foundations under columns tied by foundation beams were chosen as foundation solution. These foundations transmit the exterior loads to the soil through isolated foundations. In order to establish effective pressure and the necessary reinforcement in the foundations, there were computed the loadings transmitted by the columns and the walls.

1.6 Technical requirements for steel structures

EN1090 specifies requirements for execution of steel structures, in order to ensure adequate levels of mechanical resistance and stability, serviceability and durability, and specifies requirements for execution of structural steelwork as structures or as manufactured components.

EN1090 code will be used to fulfil all technical requirements. Several aspects are pointed out:

- the execution class for the structures as a whole is EXC2;
- all fillet welds indicated in the execution drawings are of class EXC2 (EN ISO 5817 Quality level C generally);
- all but welds indicated in the execution drawings are of class EXC3 (EN ISO 5817 Quality level B);
- all connections with non-preloaded mechanical fasteners shall be visually checked after they are bolted up with the structure aligned locally;
- geometrical tolerances are according with Chapter 11 and Annexe D of EN1090;
- corrosion protection: surfaces should be painted according with EN ISO 12944 series and Annex F;
- the structure shall be cleaned to prevent damage by corrosion.

The application of a building design in Romania should be approved by an Authorised Proof Engineer. It should be mentioned here that Professor Dan Dubina is charted as Proof Engineer. The use of the project in different conditions (location, loadings, layout, purpose, quality of materials) than was design cannot be done without the written agreement of the designer. On the purpose of application the Building Permit has to be obtained from local authority.

2. Structural drawing list

Drawing No.	TITLE
F01	Foundation Plan
F02	Foundation Beams Reinforcing Plan
F03	Foundation F1
F04	Welded wire mesh reinforcement plan Level -0.04
SM - 01	3D View
SM - 02	Encased Footing Elements
SM - 03	Frame Ax1
SM - 04	Frame Ax2
SM – 05	Frame Ax3
SM - 06	Frame Ax4
SM - 07	Frame AxA
SM - 08	Frame AxB
SM - 09	Plan Level +2.84
SM - 10	Plan Level +5.82
SM - 11	Trapezoidal profiled sheet plan Level +2.84
SM - 12	Trapezoidal profiled sheet plan Level +5.82
SM - 13	Welded wire mesh reinforcement plan Level +2.84
SM-14	Secondary Structure - Wood studs : AxA
SM-15	Secondary Structure - Wood studs : AxB
SE-01	Assembly Pi1
SE-02	Assembly CVP1
SE-03	Assembly CVP2
SE-04	Assembly GP1
SE-05	Assembly RL1
SE-06	Assembly RL2
SE-07	Assembly RL3
SE-08	Assembly RL4
SE-09	Assembly RPP1
SE-10	Assembly RPP2
SE-11	Assembly RPP3
SE-12	Assembly RPS1
SE-13	Assembly RPS2
SE-14	Assembly S1
SE-15	Assembly S2
SE-16	Assembly S3
SE-17	Assembly S4
Parts	Pa1-Pa6; P1-P31

For complete working drawings see attached folder D.2.1.e-drawings.

D.2.1.f. Quantity survey

- Prices for calculation are as for November of 2009;
- For a 150 sqm. house, taken as an individual built unit, the prices are as follows:

Summary calculation

	Euro	Euro /sqm
Materials:	36,998	246.65
Labour:	11,377	75.84
Electrical, heating, plumbing and sanitary (incl. labour):	8,000	53.33
Total:	56,375	375.83
Gross profit at 4%:	2,255	15.03
Builder's price:	58,630	390.86
VAT:	11,140	74.26
Grand Total:	69,769	465.12

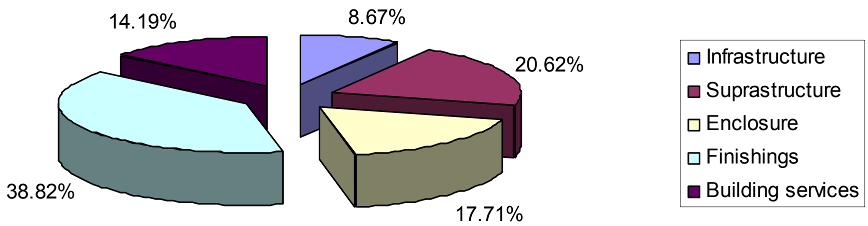


Fig. 11. Distribution per components

The above prices are for a single built unit. Obviously, a larger development, let's say 100 units, would definitely mean at least 5-10% less per unit or 355.3 Euro/sqm. or 53,299 Euro (VAT excluded).

D.2.1.g. Bill of materials

D.2.1.h. Achieved quality and performance

The quality and performance achieved are referred to:

- Enhanced quality of design and construction, and safety standards;
- Diversity of solutions for layout and envelope design;
- Modularity;
- Faster fabrication and erection;
- Easy to combine with timber and other materials;
- Thermo efficiency of cladding system (ease adaptable to client demands and in-time improvement);

- Allows for a more accurate budget estimate and cost control;
- Allows for a large variety of finishing;
- Overall lower construction cost;
- Sustainable solution; complete recycling of the steel frame structure and trapezoidal corrugated steel sheet for floor decks;
- Enhanced ambient quality and significant savings on the energy bill (including advantage for natural light, natural ventilation).

D2.2. Socio – economical assessment

D.2.2.a. Economical evaluation

Economic evaluation starts the construction budget for the house alone.

Nevertheless, the total investment cost for the property has to include the price of land (price of the land depends on the location), utilities, landscape features, design and legal fees as well as applicable taxes. For an actual economic evaluation, all this parameters have to be introduced in the equation. The difficulty is that, usually, the comparison yardstick on the market is only the builder's selling price/sqm. That's why putting together a complete financing package from the start, it is a challenge.

The demand for mortgage loans increased slightly in the third quarter, aided by the First Home scheme which failed to provide a strong stimulus to the market and hence made little difference.

The "Prima Casa" ("First House") program aimed at helping young people and young couples to acquire a home. For a 60,000€ loan, the program is directed only to certain segments of the population, with monthly incomes above 4,500 lei (approx. 1,000€). The eligible situations are:

- Individuals who do not have a home (e.g. apartment or house), individually or jointly with their spouses or other persons, regardless of how this property was acquired;
- Persons who are not in place a mortgage;
- Individuals or families who meet the conditions imposed by donors;
- People able to pay in advance at least 5% of the purchase price of the house, if the price is less than or equal to 60,000€, e.g. 3,000€. In case the price of the house is higher, then 3,000€ plus the difference between the purchase price of property and 60,000€. The maximum reimbursement period is 30 years;
- The interest rate applied to the loans granted through this program is variable, namely: ROBOR 3M + 2%, for the loans in lei and EURIBOR 3M + 3,75% for EUR .

D.2.2.b. Comparison with traditional housing concept and material

The proposed architectural design is versatile to the point that it can evolve to either towards a modern or vernacular expression. The difference when compare with a traditional house is more of technological nature than morphological ones.

In respect to architectural form and expression, the solutions presented here show that the concept is adaptable to a variety of urban and suburban configuration, i.e.: flat roof, pitched roof, variation of colour palette etc.

D.2.2.c. Achieved cost reduction

Cost reduction has to be compared with a traditional housing concept having the same size and morphology. While discussing cost reduction is paramount to recognize that a traditional house built to the same standards as the proposed design, comes to a higher price than the current offer on the market.

The 400€/sqm. price represents actually a low price for a house located in an urban area, even for a traditional solution. On the other hand, it is difficult to imagine a traditional house at such a price of a comparable quality as the one achieved by the present project.

D.2.2.d. Social advantages

The proposed design, detailed for a unit of 150 sqm. is intended to address young couples, couples with one, two children, or couples with their parents. The living area is large enough to accommodate more simultaneous activities. The one storey unit of 75 sqm. addresses primarily the young couples as a first home.

The possibility to erect the house into two phases (see D.2.1.a: *Phase 1:* house type 1 designed to support structurally another floor; *Phase 2:* addition of a new floor) encourages young families to benefit for attractive financing programme to build new homes.

If we were to go further into urban planning, one could envisage neighbourhoods made of such affordable houses, which could concentrate a younger population which in turn could support a range of retail outlets and services.

D.2.2.e. Possible deployment

As explained in D.2.2.a, the financing package for an affordable house, according to the present project, could be covered by the **"First home" program (Programul "Prima casă").**

A most important issue is land acquisition. Given the selling price of land plots before 2009, followed by the sharp decrease, one could expect a slow recovery. Going prices for land plots today, are 30-40% lower than before 2009. Even though, for a young couple, land acquisition, becomes a big problem, as banks do not finance it.

A system which was and is still used is to build on concessioned land with an agreement for 50 years, renewable another 49.

Providing an appropriate location and a financial package, the construction of the prototype becomes available and will definitely be the necessary step leading to implementation of the project.

D.2.2.f. Possibility for demonstration

Following the idea of building on concessioned land, a reasonable way to demonstrate the concept, would be to build show-homes in the new planned developments, built either by the financing party or by the one owning the land, or by both, as an incentive to buy the product.

[1] D. Dubina, V. Ungureanu, ***M. Mutiu***: *Sustainable building structures for housing*. International Conference on Sustainable Buildings 2007: Sustainable Construction. Materials and Practices, Vol. 2, pp. 1096-1103, ISBN: 978-1-58603-785-7, IOS Press, Lisabona, Portugalia, 12-14 septembrie 2007.

[2] D. Dubina, V. Ungureanu, ***M. Mutiu***: Sustainable mixed building technologies applied to residential buildings: some Romanian examples. Cost C25 - Proceedings of the first Workshop: Sustainablility of Constructions, Integrated Approach to Life-time Structural Engineering, pp. 3.93-3.102, ISBN: 978-989-20-0787-8, Lisabona, Portugalia, 13-15 septembrie 2007.

[3] V. Ungureanu, ***M. Muţiu***, D. Dubină: *Soluţii constructive pentru clădiri de locuit compatibile cu conceptul de dezvoltare durabilă.* Acta Technica Napocensis. Section: Civil Engineering – Architecture. Proceedings of the International Conference – Constructions 2008, 9-10 May 2008, Cluj-Napoca. Nr. 51, vol. 1, 2008, pp. 451-460. ISSN: 1221-5848.

[4] C. Arghirescu, ***M. Mutiu***, D. Dubina, V. Ungureanu: *Sustainable Block of Flats: A Romanian Example*. 1st International Exergy, Life Cycle Assessment, and Sustainability Workshop & Symposium (ELCAS) 4 - 6 June, 2009, Nisyros – Greece, ISBN: 978-960-243-663-9, pp. 141-148.

[5] Dubina D., Ungureanu V., Ciutina A., ***Mutiu M.***, Grecea D.: Innovative sustainable steel framing based affordable house solution for continental seismic areas. Proceedings of the First International Conference on Structures and Architecture, ICSA 2010, Guimaraes, Portugal, 21-23.07.2010, p. 367-368+CD.

[6] Dubina D., Ungureanu V., Ciutina A., Tuca I., ***Mutiu M.*** Sustainable single family house - case study. Proceedings of the International Symposium "Steel Structures: Culture & Sustainability 2010". 21-23.09.2010, p. 603-612.

[7] Dubina D., Ungureanu V., Ciutina A., Tuca I., ***Mutiu M.***: Sustainable detached family house - case study. Journal of Steel Construction. Design and Research. (3)2010, 154-162.

[8] Programul international COST C25: "Sustainability of Constructions - Integrated Approach to Life-time Structural Engineering"; perioada 2006-2010. Beneficiar: Fundaţia Europeana pentru Ştiinţă ESF.

[9] Proiectul Affordable House Project, perioada: 2009-2010, Beneficiar ArcelorMittal Liege Research.

References

[1] Thomas E. Uher (1999) - *Absolute Indicators of Sustainable Construction*
[2] John P. Glyphi (2001) *How Can the Architect Contribute to a Sustainable World*
[3] Carol Boyle (2004) *Sustainable Buildings in New Zealand*
[4] United Nations Environment Programme (2007) - *Buildings and Climate Change*
[5] A.D. Ibrahim and A.D.F. Price (2006) *Impact of Social and Environmental Factors in the Procurement of Healthcare Infrastructure*
[6] Luís Bragança et. al. *COST Action C25 Sustainability of Constructions Integrated Approach to Life-time Structural Engineering*
[7] APEGBC (1995) *Guidelines for Sustainability*
[8] Jonathan M. Harris (2000) *Basic Principles of Sustainable Development*
[9] S. Sebake (2009) *Limitations of Implementing Sustainable Construction Principles in the Conventional South African Design Approach*
[10] Adam Mannis (2002) *Indicators of Sustainable Development*
[11] Braganca et. al. (2005) *Sustainable Design Principles in Construction Sector*
[12] Sieglinde Fuller (2010) *Life-Cycle Cost Analysis (LCCA)*
[13] CIIITC Centre for Excellence in Sustainable Development (2007) *Sustainable Construction*
[14] Isabella Christensen (2009) *Sustainable Construction Policies in EPA Region IV*
[15] Commonwealth Association of Architects. UK (2003) *An Architect's Guide to Designing for Sustainability.*
[16] HM Government (2009) *Strategy for Sustainable Construction*
[17] John Straube (2009) *The Passive House (Passivhaus) Standard: A comparison to other cold climate low-energy houses*
[18] Wolfgang Feist (2007) *Passive Houses in Practice*
[19] Collyns Dan (2009) *Peru rebuilds two years on from quake*
[20] Ted Katauskas (2007) *Dirt-Cheap Houses from Elemental Materials*
[21] http://www.rammed-earth.info
[22] USDA Farmers' Bulletin No. 1500: *Rammed Earth Walls for Buildings*
[23] Cecelia Goodnow (2007) *Thinking of building a cob home?*
[24] Kathryn Vercillo (2004) *Ultimate Guide for Using Earth to Build Your Home*
[25] Roger Hunt (2011) *Sustainable Brick*
[26] Myhrman Matts; S.O. MacDonald (1994) *Build it with Bales*
[27] Iyad (Ed) M. Alsamsam (2004) *Sustainable High Performance Concrete Buildings*
[28] D. Dubina, V. Ungureanu, R. Landolfo (2011) ECCS-CECM-EKS-European Convention for Constructional Steelwork - Ch. 8
[29] Sigfried Giedion (1962) *Space, time and architecture: The growth of a new tradition*
[30] http://en.wikipedia.org
[31] Paul J. Armstrong *From Bauhaus to m-[h]ouse: The Concept of the Ready-Made and the Kit-Built House*
[32] Donald Hoffman (1984) *Frank Lloyd Wright's Robie House*
[33] Radu Patrulius (1975) *Locuinta in timp si spatiu*

[34] Moya K. Mason *Housing: Then, Now, and Future*
[35] Encyclopaedia Britannica 1995
[36] Nils Larsson IISB - The Integrated Design Process
[37] Nadav Malin (2004) *Integrated Design*
[38] NASH- Buyers Guide to Steel Framed Housing
[39] Helena Burstrand (2001) *Light-gauge Steel Framing for Housing*
[40] Canadian Sheet Steel Building Institute (2005) *The Lightweight Steel Frame House Construction Handbook*
[41] Dan Dubina (2007) *Behavior and performance of cold-formed steel framed houses under seismic action*
[42] O. Iuorio, R. Landolfo, L. Fiorino (2008) *Seismic design of cold-formed steel housing: a case study*
[43] R. Landolfo, G. Della Corte, L. Fiorino 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada (2004) *Testing of Sheated Cold-Formed Steel Stud Shear Walls for Seismic Performance Evaluation*
[44] Yalda Khorasani, Zhina Siadat (2010) *Steel Timber Hybrid Structures*
[45] P100-1/2006 *Design of structures for earthquake resistance Part 1: General rules, seismic actions and rules for buildings*
[46] Chris Arnold (2009) *Building Envelope Design Guide*
[47] I. McChesney, (2008) *Thermal Insulation in New Zealand Homes*
[48] Sean M. O'Brian (2008) *Thermal Bridging in the Building Envelope*
[49] Dale Dorman (2008) *Moisture Control in Homes*
[50] Anton TenWolde (1998) *Indoor Humidity and the Building Envelope*
[51] John Straube (2008) *Air Flow Control in Building*
[52] John Straube (2001) *Understanding and Controlling Airflow in Buildings*
[53] P. 0. Fanger (1973) A*ssessment of man's thermal comfort in practice*
[54] Peter Lyons, Dariush Araste (2000) *Window Performance for Human Thermal Comfort*
[55] Austrian Energy Agency (2008) *Promotion of sustainable cooling in the service building sector*
[56] W. Grondzik, R. Furst (1996) HVAC Components and Systems
[57] A. Bhatia *HVAC Refresher – Facilities Standard for the Building Services*
[58] Jim Sinopoli (2009) *How Do We Measure The Performance Of A Building?*
[59] Mtech Consult Limited *Waste Reduction Potential of Offsite Volumetric Construction*
[60] The Steel Construction Institute (2000) *Value and Benefits Assessment of Modular Construction*
[61] Russell A. Parnell (2008) *Vibration Serviceability and Dynamic Modeling of Cold-Formed Steel Floor Systems*
[62] Lei Xu (2008) *Floor Vibration Performance of Lightweight Cold-Formed Steel Framing*
[63] Oliver Hechler et. al. (2008) *Design Guide for Floor Vibrations*
[64] Peter Trebilcock and Mark Lawson- *Architectural Design in Steel*
[65] Jackie Craven *Life in a 1900 House*
[66] Stanley Abercrombie (1990) *A Philosophy of Interior Design*
[67] *Arhitectura Magazine, nr. 78, Oct. 2009*
[68] Werner Sobek - *Arhitectura Magazine, nr. 82,March 2010*