International Journal of Multidisciplinary Thought,
CD-ROM. ISSN: 2156-6992 :: 3(4):141–156 (2013)
Copyright © 2013 by UniversityPublications.net

LIFE CYCLE ASSESMENT OF LIGHT GAUGE STEEL FRAMING; INDUSTRIALIZATION AND GREEN BUILDING

Semih Goksel Yildirim

Istanbul Arel University, Turkey

Light gauge steel framing, little exposed to earthquake forces due to its lightness, brings the usage of less amount of structural members than other alternative structural systems. Light gauge steel framing is prefered during selection of structural system of a low rise residential since having the properties of rapid installation, minimized construction waste and the potential of recycling of structural members, etc. Selection of structural system is not only the selection of the used structural members, but also selection of the life cycle of a building including periods; design, production, assembly, utilization and disassembly. Criterion used in selection of an industrialized building system of which distinguish as design, production and installation process match up with criterion used in building life cycle assessment. The phases of production, assembly, utilization and disassembly of light gauge steel framing for low rise residential are analysed in this study. The effect of galvanized profiles to green building rating systems are introduced and the study is expanded through a case study in Turkey. Utilization phase is evaluated as maintenance, repair and adaptation to change, and disassembly phase is subjected to potential of structural member recycling. Due to its potential of mass production and environmental concern, number of companies serve to execute light gauge steel framing structures is increasing in Turkey.

Keywords : Life cycle assessment, Light gauge steel framing, Industrialization, Green building

Introduction

Selection of structural system for a building is not only selection of used structural material, but also selection of life cycle period of a building including design, production, installation, utilization and demolition phases. There are variety criterions for designers and manufacturers during selection of a skeleton system. Rapid installation and consistant quality properties of building industrialization come to agenda in developing countries since having high population growth and housing demand. On the other hand effective usage of sources and materials is the other issue in construction industry that defines as sustainable building. Environmental performance and industrialization aprouches are matching up in some intersections of which an assessment is required. Henceforth, this study focused on this intersection of these two approaches [1]. Life cycle assessment of light gauge steel framing system as an industrialized building system is presented in this study in the context of sustainability.

International council for research and innovation in building and construction located in Netherland studied on approaches of building industrialisation. The existing strategies for industrialisation in construction can be divided in two categories, each with its own typical approach [2]:

a) **Product industrialisation;** focuses on the technological aspects of building. On-site and off-site industrialisations are both examples of product industrialisation.

- **On-site industrialisation.** Some examples are GPS-positioning, assembly of big prefabricated units, identification of elements with bar-codes, just-in-time deliveries, self-climbing formwork, self-levelling concrete, robotic finishing applications, etc.
- **Off-site industrialisation.** Based on the assumption that buildings may also be made in factories. Increasingly bigger and bigger elements are factory made and transported to site. The ultimate goal is a radical change that will lead to new buildings, fully constructed with prefabricated elements assembled on site, ready for use.

b) **Process industrialisation;** concerned about how parties are cooperating, contractually and informally. It deals with Design and Build contracts.

Light Gauge Steel Framing System

Ease of production, transportation, mounting and installation properties of light gauge steel framing system are the choice reason of structural system for low rise residentials. On the other hand, being a light structure results in good performance under earthquake forces. Main difference of cold formed steel frame and timber frame systems is; using hollow section conductive constructional steel material instead of solid section wood with high insulation value [3] (Figure 1). Residential steel framing members were originally designed as a substitute for wood framing. However, they are now being manufactured in systems which reflect the superior strength and consistency of steel [4].

Alternative industrialised “dry-construction“ building solutions with light gauge steel framed structure are becoming more popular, presenting some advantages (economical, functional, environmental, etc.) in comparison with the traditional construction techniques (Figure 1). Furthermore, rapid on-site erection, ease to prefabricate and mass production allowing for accurate detailing and better quality control, economy in transportation and handling and offering great potential for recycling and reuse are the main advantages of light gauge steel framing system. Moreover the number of companies specialized in executing these types of solutions are growing and the prices are becoming more competitive [4].



Figure 1. Light gauge steel framing construction for low rise residential (Kardelen Houses, Boğazköy, Istanbul, Turkey).

Low-rise light-weight steel buildings, despite their size and complexity, are very good products for mass production. Steel construction, by it‘s nature, is prefabricated to some degree. There are three basic residential steel framing assembly methods: a) stick built construction; b) panelised systems; c) modular/volumetric construction [4].

Construction elements of a framed house are devided into three main assemblies: floors, walls and roofs. The steel component known as the structural C is the most used shaped [4]. Light gauge steel framing system is a construction technology using cold-formed steel as the construction material. It can be used for roof systems, floor systems, wall systems, roof panels, decks, or the entire buildings. They can also be used as individual framing members such as studs, joists, headers, and truss members [5]. Steel structures require less material (both reduced weight and reduced volume) to carry the same loads as concrete or masonry or wood structures [6]. Cold-formed steel framing is sheet steel that is formed into shapes and sizes that are similar to what builders are accustomed to seeing in dimensional lumber (x4, x6, x8, x10, x1, and so forth) [7].

Sustainability Issues In Steel Structures

Sustainability is defined to have three dimensions: environmental, social and economic [4] [8]. In many countries, sustainability focus is on reyclability. Sustainable construction can in many cases be achieved by “knowing before doing“. By life time thinking, efficient use of durable and recyclable materials, and by careful construction using the best suitable components as intended sustainability improvements can be reached [9]. Steel construction enables efficiency, durability and recyclability. For example the material efficiency, the relatively low weight, and the high recyclability of steel structures are directly linked to e.g. less use of resources, less use of energy, less waste, less emissions and less transports [9] (Table 1).

Table 1. Attributes of steel in sustainable construction [9].

Attribute	Comment on steel construction
Usability	Steel construction is pre-fabricated in efficient factory processes with minimum use of resources, and enables long span, high-rise and flexible building
Speed	Steel structures are installed rapidly on site which reduces local disruptions
Weight	Steel structures are light, and therefore efficient on materials, energy, transports and emissions. The low weight also enables vertical extension and optional location
Waste	Steel construction is very material efficient, generating low amounts of waste, and most of the waste is recycled
Performance	Steel is high performance, dimensionally accurate material, produced with modern computerised technology
Logistics	Steel structures are delivered to site "just in time" for installation, and can be produced loacally
Durability	Steel structures have long design life and the high quality remains
Health	Steel construction is dry construction, low-emitting materials, controlled and safe process and leads to high quality architecture
Recyclability	Steel buildings or components can be dismantled and re-used

Sustainability was defined nearly thirty years ago as "progress that serves the needs of the present without compromising the ability of future generations to meet their own needs“ [10]. It is commonly accepted fact that the steel presents a lot of positive environmental impacts as being the effective reasons of consumer preferences regarding; sustainability, refurbishment, recyclability and reusability issues [11]. As the world population grows faster than before, increasing amount of material consumption creates also the problem of increasing waste and increasing pollution. Therefore it is almost a common goal for the societies to prefer consuming environment friendly products in their daily lives [11].

Life Cycle Assesment of Light Gauge Steel Framing System

Sustainable construction material is the material using less energy during production, installation, utilization and demolition phase, having minimum effect on environment and not being harmfull to human health. Each period defined above have different effect on the environment. In order to determine environmental performance of the materials, life cycle assesment approach is being used. Distinguishing different periods of evaluation is the key aspect of finding environmental effects [1].

Production, installation, utilization and demolition phases are accepted for assesment (Table 2). Energy usage during production of raw material, number of process during production, storage etc., during production phase, transportation, structural weight, workmanship level etc, during installation phase, adaptation to user requirements, maintenance cost during utilization phase, recycling and re-use of structural materials during demoliton phase are the examined items for life cycle assesment [1] (Table 2).

There is a difference between evaluation of structural material and structural system as shown on Table 2. Each criterion has different importance ratio during decision making process. Which item will be the most important during selection period of a structural system can defined by designers and manufacturers due to their projects worked on [1].

Table 2. Assesment phases for life cycle of light gauge steel framing [1].

PRODUCTION PHASE						INSTALLATION PHASE						UTILIZATION PHASE			DEMOLITION PHASE	
Energy usage during production of raw material	Production series	Type of material used	Number of process during productrion	Production Duration	Storage	Member Supply	Transportation by	Structural Weight	Tools for Installation	Workmanship Level	Design Change During Installation	Adaptation to User Requirements	Maintenance Cost of Stuctr. Members	Maintenance Cost of Plumbing System	Recycle of Structural Member	Re-use of Structural Member
Low (1/3 of last 30 years	Little amount	One Type (Galvanized Steel Plate)	One (Roll Forming)	One day	Small Space	Rapid	Light Com. Vechile	Light	Hand Tools	Low	Applicable	Applicable	Low	Low	Applicable (100%)	Applicable

Production Phase

- Material Properties of Galvanized Steel Profiles;

Unlike structural shapes that are hot rolled into shape, manufacturing of lightweight steel framing is carried out at ambient temperature, hence the term cold formed. Because of manufacturing process is fast, there is no need to carry manufactured product in stock. Light gauge steel framing can therefore be custom manufactured to fit specific job requirements including precise cut-off lenghts and web cut-out locations [12].



Figure 2. Production of structural steel profiles by roll forming of galvanized steel plates in factory (Kosk Celik Yapı Factory, Pendik, Istanbul, Turkey).

Basic properties for galvanized steel profiles are shown below;

- Less weight (yet very strong) than wood members and concrete results smaller foundations, less excavation and less probability of damages in an earthquake [5]
- Steel will not rot. Steel frames stay straight, unlike timber which can move and warp, twist and shrink during and after construction [5]

- Long term maintenance costs are reduced because steel is resistant to rot, mold, termite and insect infestation [7]
- Steel is non-combustible and won't contribute to the spread of a fire **[5]**
- Steel's high strength-to-weight ratio is exploited in building structures, giving low overall environmental impacts [9]

It is also very important to note that, promoting steel as the alternative way of building system against wood is a very positive and effective environmental approach in considering the destruction of trees and thus the scarcity of our forests. While it is predicted that the iron ore resources will last 7 million years with today's mining activities; it is not easy to renew the diminished forests especially within a short period of time. It is also important for our environmental values to note that; the energy need to produce 1 ton of scrapbased steel is about one fifth of the ore-based steel [11]. Framing with steel consumes only % 6,3 (embodied energy) of the total life-cycle energy used by a home; while the rest is consumed by heating, cooling, refrigeration and lightning (operational energy) [11]. A home is one of the few necessities that consumers expect to last a lifetime or more. Galvanizing is one of the most economical and effective ways to protect steel. Steel framing materials used in residential and light commercial construction can be effectively protected by a galvanized coating [13]. Steel used for framing will last from hundreds to over a thousand years due to its zinc coating [6]. And a study, conducted by the NAHB Research Center, showed that the zinc coating on steel framing materials can protect against corrosion for hundreds of years [7].



Figure 3. Zinc coated members (Aksan Yapı Factory, Çorlu, Tekirdağ, Turkey).

The durability of zinc-based coatings is a function of time of wetness and composition of the atmosphere. Since residential galvanized steel framing is intended for dry indoor environments, the corrosion rate of zinc should be very low. According to the corrosion rates and the minimum coating thicknesses, zinc based coatings can protect steel for the design life of the structure [13]. The corrosion rate of zinc coatings in an indoor atmosphere of a building's structure is generally low. According to a three-year British Steel study, the corrosion of zinc is lower than 0.1 μm (microns) per 3-year period in houses located in different rural, urban, marine and industrial atmospheres (Figure 4). This indicates that under similar conditions a 10-μm (microns) zinc

coating should last for more than 300 years [13]. Zinc and zinc alloy hot dip galvanized coatings are economical and recommended methods of providing long-term corrosion protection of steel framing members [13].

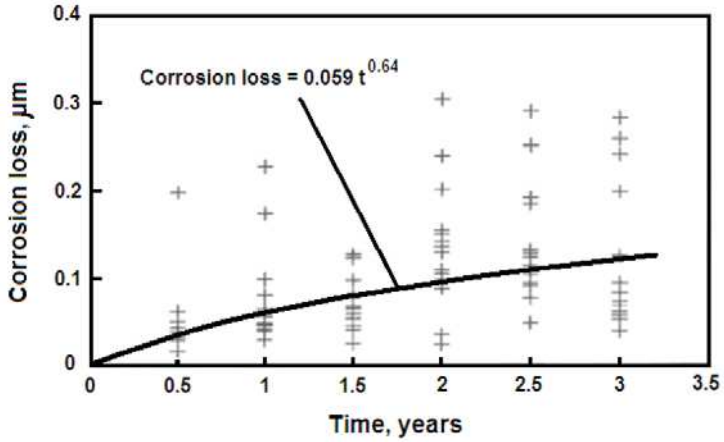


Figure 4. Corrosion loss of galvanized steel, exposed in the loft of 15 residential houses located in three different geographical areas in UK, as a function of exposure time [4].

- **Building Physics**;

Steel frame buildings do not settle or warp, so they remain more airtight [5]. Good indoor air quality (IAQ) is promoted because steel does not emit volatile organic compounds (VOCs) [7]. In general, the effect of a structural component in an exterior wall is to act as a "thermal bridge," that is, it provides a path for conducting heat rapidly. Steel is more conductive than some other building materials but it is only one of several components in a building assembly [10] (Figure 5).

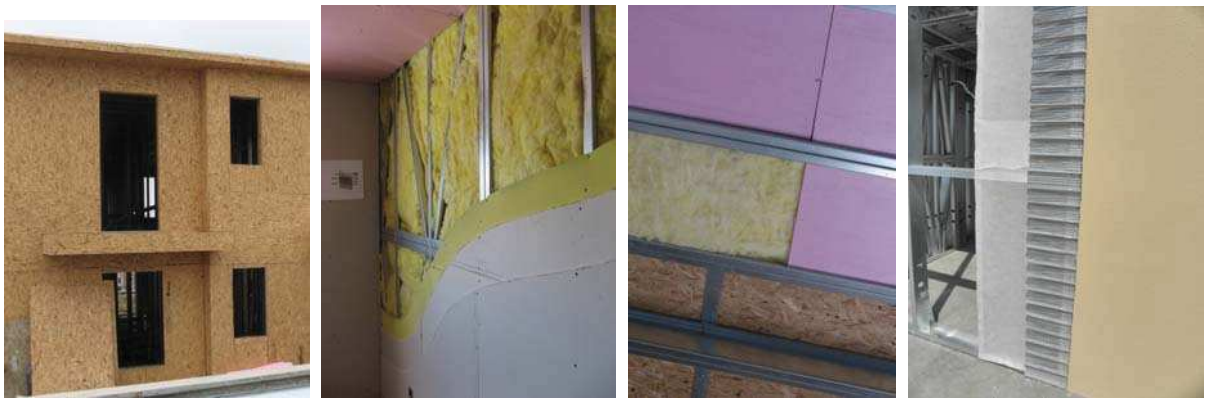


Figure 5. Building envelope samples by OSB, gypsum board, foam board and glass wool.

The dry and inorganic materials in steel construction disable possible moisture problematics during delivery, erection and completion, making the construction work easier and more cost efficient [9]. The building sector accounts for an important share of energy consumption. In Europe this share is about 40% of all energy consumption. In general terms, the major categories

of residential energy consumption are; heating, cooling, hot water production, lighting and other appliances. It can be seen that the share of energy consumption dedicated to achieving thermal comfort criteria (heating and cooling) is substantial and ranges from 55& to 74%, depending on the climatic region [4]. The structural frame itself has insignificant influence on the operational energy, but the thermal efficiency of the building envelope in combination with adapted building services is important. The operational phase normally includes 85-95% of the life-cycle energy usage of a building. Small insulation improvements can have big influence on the total energy usage. [9].

- **Production of Structural Members**;

Panelization of light gauge steel framing, on or off site, extends the advantages of mass production (speed and quality control) to the fabrication of complete assemblies. Panels can also be delivered to the site with some types of finishes already installed [12]. A big part of steel construction is performed in factory, off the construction site. The prefabrication of frames, structural elements, modular units etc. provides a safer working environment, and facilitates accurate and quality workmanship [9]. Steel framing is supplied with electrical and service holes pre punched, meaning reduced time on site for plumbers and electricians [5] (Figure 6).



Figure 6. Prepunched constructional steel profiles (Köşk Çelik Yapı Factory, Pendik, Istanbul, Turkey).

Installation Phase

In light gauge steel framing construction, low weight assemblies cost less to erect. In particular, significiant savings in crane costs and installation can be realized [12]. Steel construction also simplifies the logistics, increases the speed of the construction process, and minimises the pollution and noise on site [9]. Steel is made to exact specifications, so on-site waste is minimized [15] (Figure 7). Minimising waste is a priority for the construction industry. In steel construction Computer Aided Design (CAD) systems are efficiently integrated with the manufacture, producing high quality steel products to correct and stable dimensions, generating almost no wastage on site. Any steel waste is recovered and recycled into new steel [9].



Figure 7. Construction site of light gauge steel framing system causes very little amount of waste and pollution (Zeytinsuyu Tepesi Houses, Büyükçekmece, Istanbul, Turkey).

Construction industry can be accepted as one of the important users of material and energy. That is why it gains a big importance for this sector to consider energy savings, renewable raw material usage and minimisation of the pollution as much as possible [11]. Comparing with the concrete buildings, steel structures have lower negative environmental impact concerning the energy use, raw material consumption and created material waste [11].

Utilization Phase

Decisions made at the initial design stage have the greatest effect on the overall sustainability impact of the construction project as well as the life time of the building [9]. Designing buildings for long life and a minimum of operational burdens are key aspects of sustainable construction [9]. In times of rapid change, sustainable buildings have to be able to accomodate task changes concerning e.g. changes of use, services, electricity and IT systems. The useful life of steel buildings can be extended through adaptation of internal space, structural extension and upgrading of the climate envelope. In these ways the life cycle costs and environmental impacts are reduced as more value is obtained from the same source [9]. Ideal for expansion of existing structures, additional floors, etc. Flexibility for future expansion and relocation [5].

Demolition Phase

Steel buildings and steel construction products are highly demountable. Prefabricated frames, elements and modules can easily be removed and collected [9]. One of the biggest problems encountered after an earthquake is the demolishing of collapsed or heavily damaged buildings. If the damaged building stock consist of medium-rise buildings made of heavy and brittle construction material just like reinforced-concrete buildings, it is not easy but a real big concern to manipulate and demolish heavily damaged buildings and remove such a bulk material waste afterwards. (Figure 8) Actually this is a big serious environmental issue both considering environmental contamination during demolishing and waste removal stage and considering the created landfills which are the real damages to the nature [11].



Figure 8. Reinforced concrete building collapse at 1999 Izmit Earthquake, Turkey.

When considering this environmental case for building material selection, constructional steel comes forward as being a very competitive and advantageous building material which can be easily dismantled, repaired, fixed and reused in parts whenever required. Steel is also very suitable building material for economical material design. It can be economically used in different sectional sizes of hot rolled or light gauge forms either as framing member or as the complementary building parts [11].

- **Recyclability**:

Recycling saves money while conserving energy and resources [9] [15]. Steel is the world's most widely recycled material, and as more steel is used for construction and other products, more scrap is available for future recycling. At the end of their useful life, about 88% of all steel products and nearly 100% of structural steel used in construction are recycled into new products. It is always cheaper to recycle steel than to mine virgin ore. Unlike other competing industries, recycled content in the steel industry is second nature. The North American steel industry has been recycling steel scrap for over 170 years [15].

- **Reusability**:

Reuse offers an even greater environmental advantage than recycling. Reuse means using the demounted product again with or without any refurbishment. Reuse is not yet that common, but a certain degree of standardization is necessary [9]. In the future, the task for architecture and civil engineering research will be to develop construction systems that can be reused nearly 100%. To have no waste is a topic for future research in architecture and engineering [8].

Life Cycle Cost Assesment

When only the framing system is considered, studies have shown that a stick-framed steel system can cost 15% more than wood framing. However there are a number of savings that builders realize when they use steel framing [7]. A study has been conducted for building cost of light gauge steel framing system in circumstances of Turkey. Evaluation of life cycle cost (LCC) of a building is more appropriate instead of evaluating as only construction cost. Life cycle cost for a building covers several periods as; definition of building requirements, preparation of feasibility, design, construction, operation, maintenance, change due to user requirements and

demolishment. Life cycle cost evaluation is narrowed in this study only through structural system, henceforth included only design, installation and utilization periods. Table 3 shows the cost items structural system [16]. On the other hand, operational energy is an other issue that has to be studied as normally includes 85 % of the life cycle energy usage of a building [9].

Table 3. LCC assesment of light gauge steel framing system.

Design Cost		Installation Cost		Utilization Cost		
Structural Project	Official Approvals	Construction	Precautions Against Fire	Recycling	Maintenance	Alteration
Due to Designer	Due to sqm of a Residential	15 % More Than Timber Framing	Gypsum Board Covering Inside (Similar with Timber Frame System	Applicable (%100)	Less (Since Having Resistance to Decay and Termit Attack)	Applicable (Since Having Ease of Connection)

Green Building Rating Systems

Worlwide, a variety of assesment programs have been developed around environmental and energy impacts of buildings. The first environmental certification system was created in 1990 in the UK as The Building Research Environmental Assesment Method (BREEAM) [17]. In 1998 the Leadership in Energy and Environmental Design (LEED®) Green Building Rating System in the US was introduced based quite substantially on the BREEAM system [18]. In turn, in 2005, the Green Building Initiative (GBI) launched Green Globes by adapting the Canadian version of BREEAM and distributing in the U.S. market [19]. Although existance of other green building rating systems such as; Casbee, GBTool, Green Globes, since having worldwide reputation, BREEAM and LEED® certification systems are introduced in this study [20].

Green building rating system only promotes the use of materials with high levels of recycled content [15] [21]. Steel framing is recognized for its important environmental attributes: particularly its consistent recycled content and reclamation rate [21]. Using less energy will result in many sustainability credits. The ease of installing a steel structure also shows the ease of designing for simple dismounting, reuse and recycling of the components [9].

BREEAM Green Building Rating System

BREEAM is the world's foremost environmental assessment method and rating system for buildings, with 200,000 buildings with certified BREEAM assessment ratings and over a million registered for assessment since it was first launched in 1990. It encourages designers, clients and others to think about low carbon and low impact design, minimising the energy demands created by a building before considering energy efficiency and low carbon technologies [22]. This is a voluntary measurement rating for green buildings that was established in the UK by the Building Research Establishment (BRE). Certification levels are determined as; acceptable, pass, good, very good, excellent and outstanding.

LEED® Green Building Rating System

LEED® consists of a suite of rating systems for the design, construction and operation of high performance green buildings, homes and neighborhoods. More than 10.000 building certified under LEED® Green Building Rating System [23]. Certification levels are determined as; certified, silver, gold and platinium [18].

Light Gauge Steel Framing Residential Project Sample; 35. Sokak, Izmir, Turkey

A private firm (Aksan) known in the steel industry in Turkey is working on a 555 house complex in Izmir / Turkey, aiming to receive a BREAAM 'Very Good' rating for 5 model homes. "This project will be the first sustainable home project in Turkey [24] [25]. The project data are shown in Table 4.

Table 4. The project data [24].

Project Name	Location	Client / Developer	Contractor	Company Profile	Green Building Rating System	Rating / Score	House Number	Structural System
35. Sokak (35th Street)	Izmir, Turkey	Aksan Yapı, Istanbul	Aksan Yapı, Istanbul	Known in Steel Industry	BREEAM	Very Good / 64.57 %	555	Light Gauge Steel Framing

Figure 9 shows site layout of the project that leaving a wide green landscape on the site. Figure 10 presents structural system installation with having very less amount of waste on site and sectional properties of the houses of which seen carparking under the houses in order to use land slope and hide inside the land.



Figure 9. Site layout of the project.

Figure 11. shows the façade and inner street design derived from local architectural character of Izmir, Turkey.

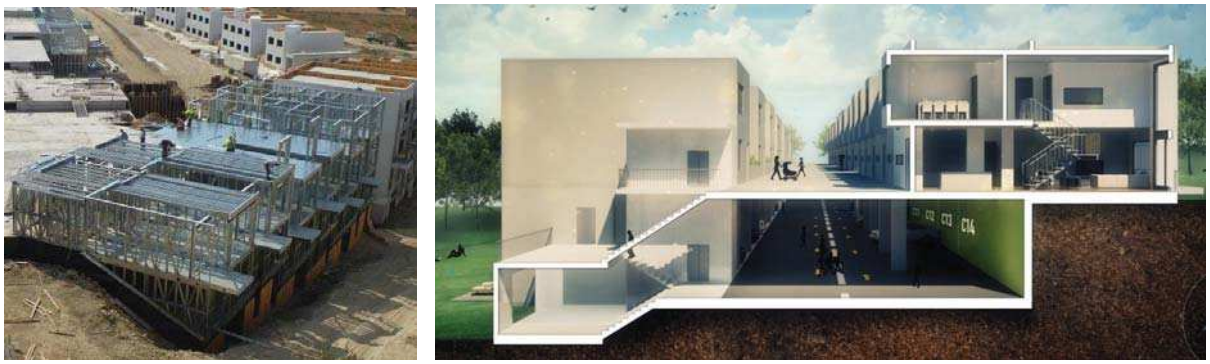


Figure 10. presents structural system installation and sectional properties.



Figure 11. Facade and inner street design.

The prominent titles of the project in terms of life cycle assessment are [26];

- positioning the buildings according to slope causes leaving more green areas to house holders and effective land use
- usage of 3600 ton constructional steel member (cold formed) for 555 houses has potential of 100% recyclable material
- usage of photovoltaic panels produces 400.000 kWh electricity causes 290 ton less carbon emission
- usage of high efficient heating and cooling system by air source heat pump causes 376.000 kWh electricity saving
- usage of grey waste water system (waste water from sink and bath first refined then used in closet reservoir) causes 40% of water conservation

Conclusion

Alternative industrialised “dry-construction“ building solutions with light steel framed structure are becoming more popular, presenting some advantages (economical, functional, environmental, etc.) in comparison with the traditional construction techniques. The prefabrication of frames, structural elements, modular units etc. provides a safer working environment, and facilitates accurate and quality workmanship. Light gauge steel structures require less material (both reduced weight and reduced volume) to carry the same loads as concrete or masonry or wood structures. The material efficiency, the relatively low weight, and the high recyclability of steel structures are directly linked to e.g. less use of resources, less use of energy, less waste, less emissions and less transports. It is commonly accepted fact that the steel presents a lot of positive environmental impacts as being the effective reasons of consumer preferences regarding; sustainability, refurbishment, recyclability and reusability issues.

It is also very important to note that, promoting steel as the alternative way of building system against wood is a very positive and effective environmental approach in considering the destruction of trees and thus the scarcity of our forests. Construction industry can be accepted as one of the important users of material and energy. That is why it gains a big importance for this sector to consider energy savings, renewable raw material usage and minimisation of the pollution as much as possible. Comparing with the concrete buildings, steel structures have lower negative environmental impact concerning the energy use, raw material consumption and created material waste. The useful life of steel buildings can be extended through adaptation of internal space, structural extension and upgrading of the climate envelope. In these ways, the life cycle costs and environmental impacts are reduced as more value is obtained from the same source.

One of the biggest problems encountered after an earthquake is the demolishing of collapsed or heavily damaged buildings. It is not easy but a real big concern to manipulate and demolish heavily damaged buildings and remove such a bulk material waste afterwards. When considering this environmental case for building material selection, constructional steel comes forward as being a very competitive and advantageous building material which can be easily dismantled, repaired, fixed and reused in parts whenever required.

Steel is the world's most widely recycled material, and as more steel is used for construction and other products, more scrap is available for future recycling. At the end of their useful life, 100% of structural steel used in construction are recycled into new products. It is always cheaper to recycle steel than to mine virgin ore. Reuse is not yet that common, but a certain degree of standardization is necessary.

When only the framing system is considered, studies have shown that a stick-framed steel system can cost 15% more than wood framing. However there are a number of savings that builders realize when they use steel framing. Life cycle cost assesment of a building is more appropriate instead of a as only construction cost. Life cycle cost for a building covers periods as; design, installation and utilization. Steel framing is recognized for its important environmental attributes: particularly its consistent recycled content and reclamation rate. Using less energy will result in many sustainability credits.

The project of 35. Sokak constructed by light gauge steel framing system is presented in this study as a sample of sustainable home project in Turkey. The prominent titles of the project in terms of life cycle assessment are designing its site layout with leaving more green areas to house holders and positioning the buildings according to slope, having less energy and water consumption, usage of renewable energy sources and recyclabe materials.

References

1. **Yıldırım, S. G.,** (2011). Evaluation through environmental impact of industrialised buiding systems for low rise residential, *Congress on Environment & Design, December 8-9, 2011,* Yıldız Technical University, Istanbul, Turkey.
2. **CIB,** 2004. Industrialisation in construction, International council for research and innovation in building and construction, retreived from *http://www.cibworld.nl* dated Sept. 09, 2004.
3. **Işık, B.,** (2001). Hafif çelik yapıların geleneksel ahşap yapılar ile benzerlikleri, Turkish Constructional Steelwork Association, retrieved from *http://tucsa.org* dated 15.07.2001
4. **Santos, P., Simões da Silva, L., Ungureanu, V.,** 2012. Energy Efficiency of Light-weight Steel-framed Buildings, *ECCS TC14 Sustainability & Eco-Efficiency of Steel Construction,* ECCS – European Convention for Constructional Steelwork, Printed in Multicomp Lda, Mem Martins Portugal
5. Light gauge framing system, retreived from *http://2.imimg.com/data2/WR/IH/MY-3631443/light-gauge-framing-system-lgfs.pdf* dated 17.01.2013
6. Sustainability - green building, *Steel Framing Alliance (SFA)*, retreived from *http://www. steelframing.org/sustainability.html* dated 26.01.2013
7. A builder's guide to steel frame construction - steel framing guide, Steel Framing Alliance (SFA), retreived from *http://www.steelframing.org /PDF/SFA_ Framing_Guide_ final %202.pdf* dated 22.01.2013
8. **Bott, H.** 2012. The dimensions of sustainability, *GreenAge, approaches&perspectives towards sustainability,* Mimar Sinan Fine Arts University, Faculty of Architecture publication, Istanbul
9. Sustainability of steel-framed buildings, Task 1206-Sustainability_DRAFT B.doc, retrieved from *http://www.sbi.nu/uploaded/dokument/files/SBI-Sustainability_of_steel_ framed_buildings. pdf* dated 05.01.2013
10. Steel and the environment, *Steel Framing Alliance (SFA)*, retreived from *http://www.steelframing.org /PDF/sustainability/SFA_Green_Brochure_2-06-08.pdf* dated 15.01.2013
11. **Coşkun, H.,** The advantages of steel in building construction regarding the environmental impacts of building materials, retrieved from *http://www.livingsteel.ru/ images/library/advsteelgreenbuilding .pdf* dated 10.01.2013
12. Lightweight steel framing architectural design guide, *Canadian Sheet Steel Building Institute (CSSBI),* retrieved from *http://www.cssbi.ca/Eng/_pdf/CSSBI-57-02.pdf* dated 12.01.2013
13. Durability of cold formed steel framing members, Technical note on cold-formed steel construction, *Cold Formed Steel Engineers Institute (CFSEI),* retreived from *http://www.cfsei.org/PDF/DesignGuides/Design.Guide.4.Durability.of.Cold.Formed.Steel.Framing. Members.Sept.04.pdf* dated 30.01.2013
14. **John, V.,** 1991. Durability of Galvanized Steel Building Components in Domestic Housing, *British Steel Technical - Welsh Laboratories*, Port Talbot, UK.
15. Steel takes leed with recycled content, *Steel Recycling Institute, retreived from http://www.recyclesteel.org/en/Recycling%20Resources/~/media/Files/SRI/Media%20Center /LEEDNov09.ashx* dated 18.01.2013
16. **Yıldırım, S. G.,** Cold formed steel framing system in Turkey - industrial development, *Eurosteel 2011, 6th European Conference on Steel and Composite Structures, August 31- September 2, 2011,* Budapest University of Technology & Economics, Budapest, Hungary.
17. The building research environmental assesment method, derived from *http://www.breeam.org/index.jsp* dated 15.03.2013
18. Leadership in energy and environmental design, derived from *http://www.usgbc.org/ leed* dated 25.02.2013
19. **Smith, T. M., Fischlein, M., Suh, S., Huelman, P.,** 2006. Green building rating systems, a comparison of the LEED and green globes systems in the US, *Univeristy of Minnesota, Sept. 2006*, derived from *http://www.thegbi.org/gbi/pdf/ProcessComparison.pdf* dated 25.02.2013

20. **Fowler, K. M., Rauch, E. M.,** 2006. Sustainable building rating systems, *Pacific Northwest National Laboratory*, derived from *http://www.usgbc.org/Docs/Archive/General/ Docs1915.pdf* dated 25.03.2013

21. Industry technical note cold formed steel construction, *Steel Stud Manufacturers Association (SSMA),* retreived from *http://www.ssma.com/filebin/pdf/ TN06_SSMA_ LEED_2.2.pdf* dated 15.01.2013

22. BREEAM Brochure, derived from *http://www.breeam.org/filelibrary/BREEAM Brochure.pdf* dated 01.04.2013

23. The green building certification institute, news and announcements, derived from *http://www.gbci.org/org-nav/announcements/11-09-08/10_000th_LEED_Building_Certified. Aspx..* dated 05.04.2013

24. BREEAM certified projects, GreenBookLive, derived from *http://www.greenbooklive.com/search/buildingsearch.jsp?id=202&productName=&sectionid=101&partid=10023& countryld =7* dated 16.04.2013

25. 2nd international green building summit, Istanbul, February 18-19, 2013, *Turkish Green Building Council*, derived from http://www.cedbik.org/default_eng.asp dated 14.04.2013

26. 35. Sokak Basın Bülteni, derived from http://www.otuzbesincisokak.com/basin/basin_ bultenleri.html dated 10.04.2013