A Study on "Temporary Post Disaster Housing Unit" Constructed with -Light Gauge Steel Framing- (LGSF) System

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ABSTRACT

Light Gauge Steel Framing (LGSF) System is a structural system made of Cold Formed Steel (CFS) Profile Frames. The structural behavior of this new construction system is derived from the traditional wooden frame systems. The new material that has been used in LGSF system which is the profile cold-rolled from sheet steel is an industrial material that needs the control of computer systems for accuracy. The structural system has been examined for more than 40 years in the construction practice. It is an alternative building material for the world and for Turkey in the last years, specifically for 1-2 storey single family houses.

This study aims to make analysis of Light Gauge Steel Framing system which is a developing construction system, to define efficient uses of the system at the moment and to propose new ones for the future. To obtain different conceptions and theories on the system has been the main goal of the evaluation part. To fulfill this goal; first, the different examples around the world have been examined in different aspects in detail to make a comparative evaluation, then, new opportunities in the usage area of LGSF system have been suggested.

"A Temporary Post-Disaster Housing Unit" has been studied as a case study. The case study is the heart of this study whereas the LGSF system has been examined by its lightweight, accurate, easy & fast montage, storable behavior characteristics as well as the structural properties. "Temporary housing" is still a demanded study for Turkey. To design a unit example with the new used LGSF system has been a study that helps both to show the benefits of LGSF in a temporary-housing and the new construction opportunity which fulfills the requirements of "a temporary post-disaster housing unit" in Turkey conditions with the Turkish building market materials.

While these issues have been worked out, the architectural approach has leaded this study. Design processes of the various examples have been inspected and the new project has been studied in a way to search –how architecture can use this system.-

ÖZ

Hafif Çelik Çerçeve (LGSF) sistem soğukta çekilmiş profillerin (CFS) birleştirildiği çerçevelerden oluşturulmaktadır. Bu yeni sistemin yapısal özellikleri geleneksel ahşap çerçeve sistemlerden esinlenilerek yapılmıştır. LGSF sisteminin yapımında kullanılan çelik yaprak elemanların soğukta bükülmesi ile oluşturulan malzeme, bilgisayar sistemi ile üretimi kontrol edilen endüstriyel bir malzemedir. Sözü edilen yapım sistemi 40 yıldan uzun bir süredir inşaat sektöründe kullanılarak denenmektedir. Son yıllarda bu sistem dünyada ve Türkiye'de özellikle 1-2 katlı aile konutu yapımında yaygınlaşmıştır.

Bu çalışma gelişmekte olan bir yapı sistemi olan 'hafif çelik çerçeve' sistemin analizini yaparak, günümüzdeki ve gelecekteki etkin kullanım alanlarını belirlemeyi hedeflemektedir. İnceleme bölümündeki ana amaç, LGSF sisteminin farklı tasarım ve teorilerini ortaya çıkarmaktır. Bu doğrultuda; öncelikle, dünya üzerindeki farklı örnekler farklı özellikleri ile ayrıntılı olarak incelenerek, dünya ve Türkiye arasında bir karşılaştırma yapılmış, sonrasında ise LGSF sistemi için yeni kullanım seçenekleri önerilmiştir.

"Geçici Afet Konutu" bu çalışmanın özgün kısmıdır. LGSF sisteminin hafif, kesin ve tam ölçümlendirilmiş, hızlı ve kolay monte edilebilen ve saklanmaya uygun yapısı ve sistemin yapısal özellikleri çalışmanın kalbini oluşturan bu bölümde incelenmiştir. 'Geçici afet konutu' Türkiye'de halen ihtiyaç duyulan bir araştırma alanıdır. 'Hafif çelik çerçeve' sistem ile tasarlanmış 'geçici afet konut birimi' önerisi, sistemin böyle bir projede getireceği faydaları ve Türkiye koşullarında üretilen sistemin yeni kullanım alanı olarak 'geçici afet konut birimi' önerisini bir arada inceleme imkanı sağlamaktadır.

Tüm bu çalışmalar yürütülürken mimari yaklaşım yönlendirici unsur olmuştur. Farklı örneklerde kullanılan farklı tasarım aşamaları incelenmiş, yapılan yeni proje çalışması ile –mimarlık yeni yapım sistemini ne şekilde kullanabilir?- sorusuna yanıt aranmaya çalışılmıştır.

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CHAPTER 1

INTRODUCTION

In this study, a new "temporary post-disaster housing unit" has been designed with "Light gauge steel framing" (LGSF) system. LGSF is a new building construction system, which is composed of cold-formed steel (CFS) profiles.

The main characteristics of the LGSF system are defined as; lightness in weight (which also makes the system an earthquake resistant system), fast production & construction, easy and fast transportation and construction, recyclability and load bearing property only up to four storey. These defined characteristics are mostly the vital characteristics of a "temporary post-disaster housing unit" so the system is thought as a challenging new alternative for temporary housing in Turkey which is one of the many suggestions that may be stated for the alternative future usage areas of the system.

1.1. Definition of the Problem

The "temporary post-disaster housing" is an important problem of Turkey and the existing designs and especially the implicated projects are been criticized in many aspects. The "temporary post-disaster housing" is a subject that's been worked by many architects and engineers, but it is still open for more studies. Because to obtain the optimum conditions defined for a shelter is hard when the designs are prepared for temporary periods. The main characteristics that distinguish a "temporary post-disaster house" from permanent houses are; easy & fast montage, demount ability, flexibility & variability, efficient new technology use with low costs.

The existing applications which had been studied in detail in various studies exhibit weakness at different points as; they are not demountable, none of them are flexible or variable in practice and mostly they cannot even obtain the standard optimum living conditions needed in a shelter, so new studies are needed with new alternative system and design approaches used in Turkey. They must be designed by learning from the previous mistakes. In Turkey, still there isn't a stock done with a chosen type of temporary shelters for disaster occasions like earthquakes that may even demolish the whole living site constructions.

It must be discovered if new construction techniques can work out the general constructional problems of the “temporary post-disaster housing units” done in Turkey. The use of new constructions that have been experienced in the country gives us the chance of building cost effective new alternatives for temporary housing. LGSF system is one of the new techniques which grow rapidly in the building market of Turkey. The characteristics of LGSF system and the “temporary post-disaster housing unit” constructional requirements overlap, so in this study these two different topics are thought to be researched together. In the guidance of the previous studies done on the temporary post-disaster housing in Turkey and using the facilities of Turkey, the project searches for a pragmatic solution.

First introduction of LGSF system into the market starts with a disaster in Turkey, 1999 İzmit Bay earthquake. The demand of new construction systems which would resist better to earthquakes imposed the interest in the entrance of new techniques and materials to the market. LGSF system has still been used by a lot of different enterprises which work on construction, whereas many of the other systems of that period had been forgotten. This system is the only effective steel construction system used in Turkey. When the LGSF building stock in the last five years is evaluated the increase in number can easily be observed. Parallel to the increase, the demand of cold-formed steel profiles for structural use increased as well and it is now possible to build the system with Turkish products.

The technological developments affect the building sector directly. There are many new construction materials and techniques derived out in order to maintain new solutions to fulfill the demands of the sector, yet the construction market mostly excludes the architectural look from the building sector in order to produce the typical, standard, cost effective products which are open to be criticized.

Light gauge steel has been a topic for several studies. The written materials on “light gauge steel” and “cold formed steel profiles” had been searched and it’s been observed that mainly, the material characteristics of the system and the material’s or the system’s behavior under different conditions had been analyzed in detail in the studies around the world, but there are only a few studies looking at the architectural designs with LGSF system.

The lack of architectural approach to the new construction systems and techniques also causes the exclusion of these systems from the architectural education and practice. LGSF construction system which is happened to be used recently more in Turkey should also be examined with the architectural approaches of some different examples. The new possible uses of the LGSF system can only be comprehended by this way and they can be converted to new designs of architects so new construction systems can enter the architecture playground as well as the building market.

Shortly, the main problems of this thesis are; 1) To discover the LGSF system and to find or develop new application areas for LGSF construction system with the eye of a designer; 2) To propose a new "temporary post-disaster housing" unit which is still needed for Turkey with LGSF, a new construction system which can be produced and constructed in the country; 3) To compare the new proposal with other "temporary post-disaster housing units" constructed with different systems, before.

1.2. Need for the study

Turkey is a country where many disasters have been faced each year, like earthquakes, floods, landslides, tornados etc. As a country that faces such disasters with an unqualified building stock, the post-disaster housing is an important subject to be studied and various different architectural projects can be studied on the same subject in order to suggest more efficient projects. There are many studies based on the "temporary post-disaster housing" which had increased in number after the 1999 earthquake. Some studies have been built after the earthquake. There are still non-built projects existing on paper, but this study is the first "temporary post-disaster housing" project which proposes LGSF as the construction system.

One of the best comparative studies done on the existing or constructed examples had been done by Berna Baradan in 2002, but the study could not get as far as constructing a new alternative. In this study by the help of the extensive thesis of Baradan, a new proposal is been searched and compared with the other examples. Comparisons done in between the new proposal and the previous "temporary post-disaster housing" systems help to define the status of the new project among other examined ones. It's hard to make comparison of a design on paper with the constructed concrete examples, but the comparative study is defined in a shape that gives chance to make a good comparison.

The "temporary post-disaster housing unit" project in this study is a design that underlines the advantages of the LGSF construction system and it also tries to solve an important problem of the country. It aims to propose an urgent solution for a future research on the temporary post-disaster housing project. This study is also needed to interrogate the contemporary facilities of Turkey in the building and construction sector and it aims to adapt the new design ideas and construction processes to the existing market structure of the country.

The studies that had been done on Light Gauge Steel Framing system in Turkey are mostly done by civil engineering departments. There are only a few studies done in the architectural departments in Turkey and none of these theses have a critical look at the LGSF examples with an architectural design approach. There are only a few short studies looking at the architectural design with LGSF system, so this study is also needed to have a look at the system by architecture.

As a growing market in Turkey, it is now possible to make comparisons of Turkey with the other world countries in this manner and observe the similarities and differences in between our country and the rest of the world, after this point. This study has the opportunity to work with the published examples on LGSF around the world and some different examples gathered around from Turkey, at the moment. This is the fact that would help this study to be the first comparative study on LGSF residential buildings in Turkey and the world, but the creative and original part of this study is still the new project on temporary post-disaster housing with LGSF system which has been produced in Turkey.

1.3. Method of the study

There are different methods used for the different parts of the study; in the first part of the study for understanding the LGSF system evaluation method has been used; the different references on the Light Gauge Steel Framing system are used to shape the general features of the construction material, construction system and construction method. The properties of the system are generally been summarized by taking information from different resources and adding the most recent improvements of the LGSF system in the world and in Turkey. The examples are chosen from the different parts of the world including different techniques of usage of LGSF system.

In the choice of the examples, first the function of the examples is defined in order to shape the design comparisons. Mainly the examples used in this study are chosen from the residential ones. The houses that have been built in Turkey in the last five years are also shown generally by a few examples. There is a common format used for giving the all (Turkey & world) examples. Examples from the world are limited with a number of 8. Various constructing methods, housing types (single family houses with 1-2-3 storey and apartment type multi family houses) and design criteria have been used to define the exact choices. The different marketing policies of the world have been marked out as well as the analysis of the building designs and constructions.

A comparative study has been done for examining the similar and different usages of the LGSF system in Turkey and the world. To shape a methodic comparison the Turkish residential examples and systems has been evaluated by comparisons with different regions of the world, like America, Australia, Europe and Japan. The integration of the Light Gauge Steel Framing system with the other construction systems is thought to be the challenging part of the system in the new future uses. For examining the different uses of the LGSF system, a general study has been added where only different structuring techniques are underlined. The functions of the different examples do not have to match, so the different examples shape the formats and contents of these examples.

In the second part (case study), both to fulfill the needs of Turkey and to show the challenging properties of the LGSF constructions have been regarded. The case study has been built with a project materialized for Turkey. The written material on "the qualifications of the post-disaster housing" is used for defining the basic requirements for such a system. The number of studies and their content is satisfactory in Baradan's thesis, so the existing study is found sufficient enough to guide the definition of the project and the requirements. The project is developed by the usage of strategically important issues like the production, the storage, the transportation and the construction steps of the LGSF “temporary post-disaster housing system” and a scenario has been shaped by obtaining both the system elements and the design process issues.

The evaluation of the project is done according to requirements defined for “temporary post-disaster housing”. After the project is understood by evaluation, to explain the project’s place among other built examples of Turkey, a comparative evaluation method has been used. To make a concrete comparison the examples and aspects to be compared must have been limited in number. It is very hard to compare a finished example which accommodated people with a project on paper even though it has been well defined and evaluated with scientific calculations. Choice of the “temporary post-disaster housing unit” for the comparative study has been done according to Baradan’s study. In her study “the container type units” are defined as the units where the user satisfaction is the maximum. “The container type units” are still been sold in Turkey for other functions, so the cost of these housing units can be obtained. The characteristics to be compared are defined as the cost and the weight which are two quantitative values. Rather than comparing the -living condition requirements- of a non-built project with one that’s been experienced by people, to compare the quantitative characteristics is more realistic.

The original part is the case study which has been tested to see if it really fulfills a gap in the “temporary post-disaster housing” for Turkey or not, in the end.

1.4. Domain of the study

With the defined methods above, the thesis has been shaped as; three chapters; in the second chapter, the development of LGSF system in the building practice has been examined both in Turkey and in the world. The structural principles of the LGSF system have been explained in detail and the constructional principles are studied. Different LGSF system elements are introduced by the help of various details and drawings. The production and construction processes of the LGSF system are sections following the general evaluation of the system part. The last section is the part where the protection and maintenance of the system has been expressed.

In the third chapter various residential LGSF building examples from the world have been searched and observed. The examples of the world and examples from

Turkey are all expressed in the same format which shows the building with its design and construction steps. First the world examples and then the examples from Turkey are held out. Each example has been evaluated according to its construction place, method and process. The different constructional details of the different systems have also been put out in each. The chapter has been continued with the comparative evaluation of the world and Turkish examples. In the following section, alternative uses of the LGSF construction system, which are mostly obtained by the integration of the system with the existing or new constructed different construction systems, is shown by different examples. The chapter is concluded with the different results (advantages, disadvantages) observed from the system evaluations and examples sections.

The fourth chapter is the case study chapter where the new proposed “temporary post-disaster housing unit” is held out. First, he design requirements of a “temporary post-disaster housing unit” system have been stated before using these criteria in the design process. The design requirements are gathered from a single study where various different studies have been collected on the subject. The new “temporary post-disaster housing unit” project constructed with LGSF system has been shaped in the direction of the requirements which is the next step in the fourth chapter. For the project, first the scenario of the production, storage, transportation and construction processes has been written down. After explaining about the project scenario, the drawings and the models of the “temporary post-disaster housing unit” system are put in the chapter. All the plans, sections, elevations, modular panel types with needed amounts and details have been given first and then by the help of the models the system and the project are concretized. The evaluation of the system is done by the help of the defined requirements at the end of this chapter.

The conclusion collects all the discovered results of part one and two. General evaluation of the case study is summarized in the beginning of this chapter. The comparative evaluation of the project with one of the existing “temporary post-disaster housing unit” design which had been experienced by the disaster people is the second part of the conclusion. In the last part, the LGSF system has been observed by picking up the probable alternative future uses for Turkey and the evaluation results of the case study part are written down. The evaluations give us the main conclusions which shows the success status of the case study.

CHAPTER 2

LIGHT GAUGE STEEL FRAMING SYSTEM IN THE NEW BUILDING PRACTICE

2.1. The Development of LGSF System in the Building Practice

2.1.1. The Reasons of the Early Use of Cold Formed Steel Profiles in the World

Cold-formed steel profiles are transferred to building industry from automotive, rail and airplane industries, like many of the other different construction materials. These profiles had been first used in automobile structures, train wagons and in bridge constructions. In the beginning of the 20^{th} century, the researches made on cold formed steel material had augmented in order to test the material for the airplane industry. In this manner, the first researches had been started in America. Many problems had been faced in the first applications of cold-formed steel which were done in 1930s because of the material's different structural characteristics. The first standards (Specification for the design of light gauge structural steel members) were derived in 1946 in America by AISI (American Iron & Steel Institute) and the last edition is published in 1986.

The first use of lightweight steel in construction had been observed as being the partition element (interior wall element). Lattice or roof elements were made of cold-formed sections. Then, this structural element had started to be used for recreational and industrial units especially in America, because of its lightness in weight and easy portability.

In construction history, although steel houses had a place in the building market since 1850s (the industrial revolution), lightweight steel construction has never had a large share of the housing market of the world up to last fifteen years. Steel housing has expanded considerably twice in this century to meet the demand arising from housing and material shortages at the ends of the two World Wars. Steel houses built just after

1919 are still in occupation and post-1945 prefabs exist in some numbers in UK and Germany. Lightweight steel elements utilization in the residential construction sector had increased after World War II. (Peter R. Knowles, 1992)

As the country which had been mostly destroyed after World War II; Germany was the place where new trends that both accepted as conventional and economic in building industry had been searched. There are some examples of the prefabrication of that time like the steel mass-produced row houses of Mies Van Der Rohe in Germany.

The search for steel systems in Germany had established new techniques of construction like the lightweight 'Hoesch Building System' (Photo 2.1) which has modular system dimensions that lie between 1.2-1.3 m with special cold-formed sections of 2 and 3 mm in size. This had been the first example of lightweight steel residential structure. It was a three-storey building built in Dortmund in 1959. (Bouwcentrum, 1963, p 213)

Also, in Japan, the use of steel frame in family houses has been common since 1950's. After World War II the house shortage was so acute that more than 4 million new houses had to be built urgently. Before 1940 most of the buildings were built of wood and fires had destroyed them during the war. To replace all the destroyed houses with wood construction would have required 150 years of timber production. To protect the forestry resources and promote non-flammable construction, the use of wood in load-bearing construction was restricted. Taking advantage of these restrictions, the Japanese steel industry began to manufacture light-gauge steel shapes as a substitute for wooden structural products to frame steel homes. As a consequence of this, a great deal of knowledge has been gained in this field and many efficient steel frame systems have been derived. Today there are a great number of standardized drawings available for residential steel homes using a frame of light-gauge steel profiles.

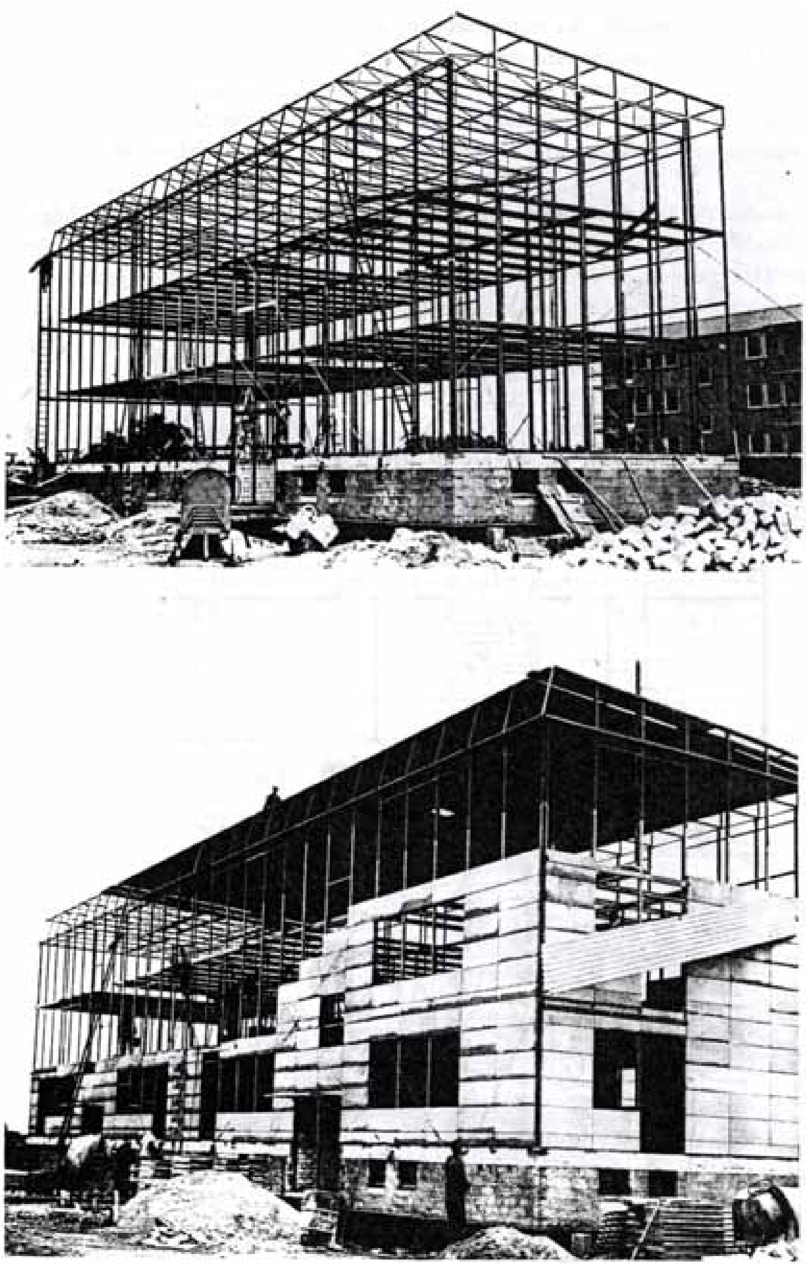


Photo 2.1 Hoesch Building System, Dortmund

In the rest of the world, the lightweight steel buildings were not common until 1990s. In the beginning of 1980s in America; the wood frame system used for housing which was economic and easily transported had changed in material. Lightweight steel frame took the place of the wooden frame system. By the increase in the use of lightweight steel in housing market; wood material became available for other more helpful uses.

"Wood-frame buildings have been built in the United States since the early settler days. American industrialization brought a new type of building individual homes called Balloon frame (1832). Balloon frame consists of nominal thick dimension lumber (two by four) in the form of joists and studs joined by factory-produced nails. Over the next few decades, home building was transformed from a specialized craft into an industry. Balloon frame construction is still in use today." (KITEK KUZMAN, KUŠAR, 2000)

The balloon frame system is the basic construction system of wood frame and 'light-weight steel frame systems' are derived from the structural principles of balloon frame. The special technique called the balloon frame is not a technique that is composed of major and minor structural element combinations. The system had been built with standard wooden structural sections that were organized simply with repetition and had been bind together by nails. The doors and windows had to be sized as the multiples of the basic spacing values. Vertical wooden wall covering elements were helping the system to be stable in wind loadings and a second covering from wooden small elements were keeping the system safe from the weather conditions. This type of structure caused the standard sized manufacturing of the wood industry (Chicago Okulu Bölüm 8). Nowadays the same of structure causes the dimensioning of the manufacturing of LGSF systems and CFS profiles.

Low-rise steel houses constructed using steel frame now account for approximately 20% of new build in the USA. Steel frame construction have a low level of wastage at the construction stage and low on-going maintenance costs in addition, between 25% and 100% of the structural steel is recycled; and is 100% recyclable. Because of these reasons, the market development for steel in steel homes in the USA has been explosive. In 1992 about 500 houses were built with a steel frame, the following year 15,000 houses, in 2002 100,000 steel houses were built, and the market looks set to continue to grow for metal homes.

Throughout the world more and more builders are switching to steel frame construction, both in low-rise and high-rise residential buildings. This internationally established and well-proven structural technique is now entering the European market. The steel frame housing favored in the UK is similar to that proven in successful office building systems. Steel houses or metal houses framed with cold rolled profiles can be assembled on the full range of conventional foundations. The Swedish multi storey light weight steel construction can be considered as the most important development of the system in Europe. The main market outside the United Kingdom has been France, Scandinavia and Denmark in Europe. These steel homes are assembled using a minimum number of construction materials; usually steel, gypsum board and mineral wool. The fast construction system has been mostly used for the ski centers' residential resort productions.

Australia is the place where low rise and separate residential buildings are built like Canada and America so the growth in the LGSF housing market is parallel too. In these countries, the designs are re-used from project to project in order to maintain economies of scale. (http://www.studchopper.com/index.html)

2.1.2. The Use of LGSF in Turkey

In Turkey 1999 earthquake had been a turning point for the building construction industry. After the 17 August 1999 earthquake, the conventional concrete building system had been highly criticized and new material and construction system researches became a new and important issue in the building market of Turkey. All authorities and also the public were interested in the research of the earthquake resistant construction materials and the systems.

The one-two storey buildings are considered to be safer than the multi-storey building types. Also the steel material is said to be a very suitable material for the earthquake zones with its elastic, light, strong material characteristics. So after the earthquake the economic steel housing system LGSF (light gauge steel framing) had been imported by some construction companies in the beginning of new millennium. The cost of these mass-produced housing systems had been still high for Turkey's economic conditions. In these last few years Turkish Construction firms became more involved with this new construction system and some started to imitate the mass-produced housing systems of the foreign pioneers.

Today there are two companies in Turkey who quitted other applications rather than LGSF. They produce light gauge steel framed houses by using mostly Turkish building industry materials and American and British standards, house design data and details. Other than these two firms that are completely involved with LGSF system; there are around 55 construction firms that are concerned somehow with this new system. Some of these firms import housing packages from Canada; America, Australia and Belgium and some produce their own system with the data of other countries. The system cost can compete with the common concrete system used in Turkey, but the real problem of this system is its transferred technology; typologies and construction details. The adaptation of this mass-produced system to Turkey's building tradition, housing expectations and comfort conditions of the Turkish people is still a critical question. The standardization in design and in building components is an important fact for marketing policies in LGSF system that may be considered as a handicap for designers. The Turkish LGSF building industry cannot improve in design concept; it only repeats itself in the examined standard typologies and promotes the new LGSF houses as "the earthquake resistant steel houses".

2.2. The Definition of Steel as a Construction Material

Steel is essentially an alloy of iron and carbon but, despite this apparent simplicity, it is one of the most complex and interesting of all materials.

(See appendix A for details)

2.2.1. Cold Formed Steel

Cold-formed steel profiles are formed by shaping the steel-sheet elements in a rolling or press-braking machine without any heat treatment. Both sections and profiled sheeting are produced in this way. Generally, 0.5 to 0.6 mm. steel sheets are shaped simultaneously or shaped by press machines (under stress) to form cold-formed steel profiles. The thickness of the steel sheets or strips used for the production of cold-formed sections vary between 0.5mm and 2,0 mm; however the majority of the sections fall within the 1.00 mm to 8.00 mm material thickness range. The overlap of the structural characteristics of cold-formed sections with hot rolled sections starts around 4.0 mm. (CIPF, 1992)

The shapes and sizes of light-gauge steel vary between manufacturers, yet the project requirements should be the first income for the material choice. The strength of cold-formed sheet steel also comes from the thickness of the material, and the profile strength comes from how the steel sheet is shaped. The production methods of the profiles are summarized in the appendix.

(See appendix B for details)

2.3. The Light Gauge Steel Construction System

2.3.1. The Structural Principles of LGSF

The general structural principles of LGSF system can be summarized with a few words. The system is composed of standard load bearing wall studs (interior, exterior), simply supported floor beams, channel runners and roof elements organized with standard in between space lengths (50-65 cm). With the help of the diagonal wind-bracing cold formed steel elements, other joint elements like staggers or the main covering element; gypsum wall board, OSB or plywood board which is attached on the whole system elements, the system structurally works as a frame which all loads are distributed on the frame itself. The foundation and roof structure of the system are designed in accordance with this loading criteria. The main structural elements of the frame (load bearing walls) are the pre-designed suitable and accurate cold formed steel sections.

The multi-storey system construction with LGSF system has problems of loading in the ground and first floors because of the explained structural system.

The specific construction data can be obtained from the last study of NASEA; The Prescriptive Method For Residential Cold-Formed Steel Framing, Year 2000 Edition.

2.3.1.1. The Similarities in the Structural System Behavior of LGSF and Wooden Frame System

"*Wood has long been the material of choice in United States residential construction. Recently, wood has been questioned as the preferred framing material because of its gradually increasing and volatile prices in addition to concerns about decreasing quality and future availability.*" (Yost, 1995)

The structural systems of LGSF and Wooden-Frame Systems have the same properties. As mentioned in the previous history chapter, LGSF system had been derived from the original wooden system as a new alternative following the demands of the world's new material challenges.

Advantages of light gauge steel construction in comparison with wooden frame system:

- Steel components weigh 60% less than wood. A 58 m^2 home requires only 6 tons of steel compared to 20 tons of lumber.
- Steel's strength and durability are higher than other materials.
- Steel construction components can be pre-measured and precut to exact specifications. On-site adjustments are generally not required.
- Steel has a consistent quality because it is a manufactured product and during construction there is not the 10-20% material waste that is typically experienced with wood framing operations.
- Steel is simply impervious to termites and other damage-causing bugs and pests.
- Steel stays straight, while wood may warp or crack.
- Steel is noncombustible, while wood is.
- Steel components generate minimal waste and all light gauge steel construction materials are 100% recyclable. (Weirton Steel Corporation, 1995)
- Load-bearing steel stud walls acoustically perform better than wood stud walls. (Brown and Swartz, 1994)
- For the same span CFS profiles required are smaller in depth compared to wood studs.

- LGSF frames have longer space in between (406 mm, wood: 365 mm), this helps the application of ventilation systems.
- The LGSF walls are 7 times stronger than wooden wall that has the same thickness.

Disadvantages of light-gauge steel construction in comparison with wooden frame system:

- Steel is an excellent thermal conductor requiring additional exterior insulation or thermal breaks to overcome this disadvantage. Thermal conductivity is probably the most serious of steel's disadvantages. This means that better exterior insulation is necessary to economically maintain the desired temperature of a home's interior during both cooling and heating seasons.
- Because light-gauge steel frame construction is relatively new and innovative within the residential construction industry, it is not only unfamiliar to craftsmen but it is also unfamiliar to engineers and code officials. The learning curve of builders and craftsmen may be slow until these individuals become familiar with the new skills required to construct with steel.
- In addition to the labor training required to convert to the use of steel, builders and laborers must obtain some new tools not presently used by carpenters. (Yost, 1995)
- In America, nearly all the building systems including light-gauge steel market, standard size structural members that have evolved were based upon conventional lumber dimensions. The reason was to be able to use the existing components such as prefabricated door and window units. Consequently light gauge steel members are the same size as wood frame structural members. Similarly, the sheathing and interior wallboard systems are based upon the use of standard panels.

2.3.2. The Constructional Principles of LGSF System

Light Gauge Steel Framing System explained in detail in this section is a system similar to wooden-frame system (the balloon frame system) and the system works just like the wooden-frame system under loading. Instead of the major structural elements; the wall elements in the system take the loads; so the wall elements are designed by modularly divided cold formed steel profile replacement. The base construction also follows the traditional wooden-frame housing system with continuous type. The CFS sections in the walls are joined together by the covering board elements or staggers. Wind bracing profiles are used at needed points. The system elements are bind together by the help of the connection elements or welding. The roof and floor elements can also made of the lightweight steel material; so the systems' dead load can be minimized.

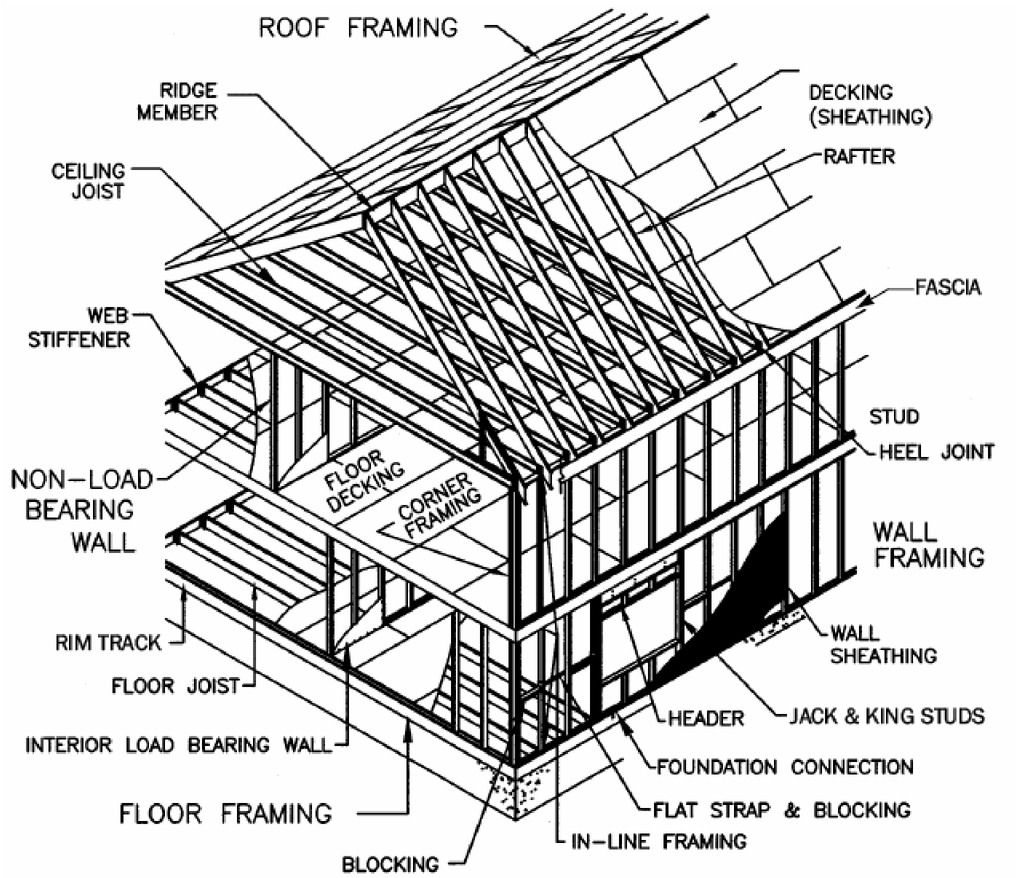


Figure 2.1 The Construction System of LGSF House

2.3.2.1. The LGSF system elements

2.3.2.1.1. The wall elements

Wall studs are cold-formed steel sections that have a wall material attached to both flanges. The sheathing element can be gypsum board, plywood or fiberboard. Wall studs can be used as load bearing elements in light residential and commercial buildings. Since the shear diaphragm action of the sheathing material can increase the load carrying capacity of wall studs significantly, the increase in maximum allowable load is considered in design. (Doksatlı, 2000)

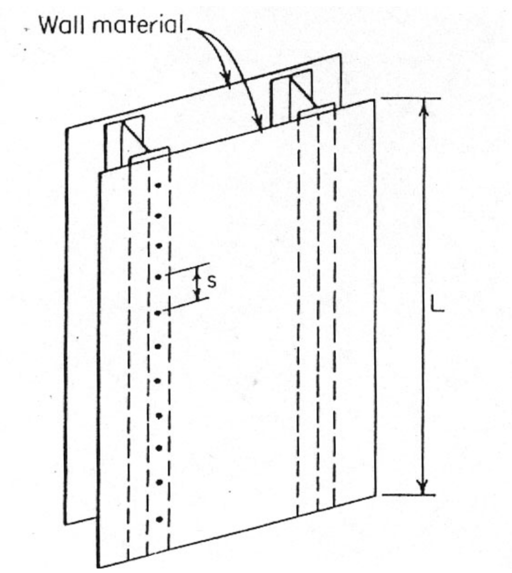
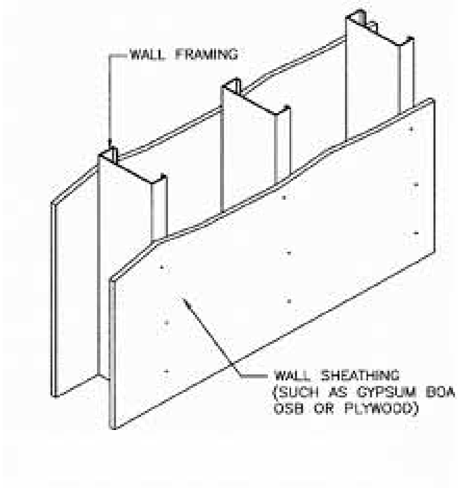


Figure 2.2 General wall system of LGSF

For selecting wall stud section, shape and thickness of the profiles should be considered. Mostly C and Z sections are used for residential constructions. The wall elements are attached to gypsum boards by the help of the connection elements. The gypsum boards help the integration of the wall studs; help them to act together under loading as a total wall element that takes load itself. Otherwise the wall studs can be fixed by horizontal steel strapping. (Figure 2.3)



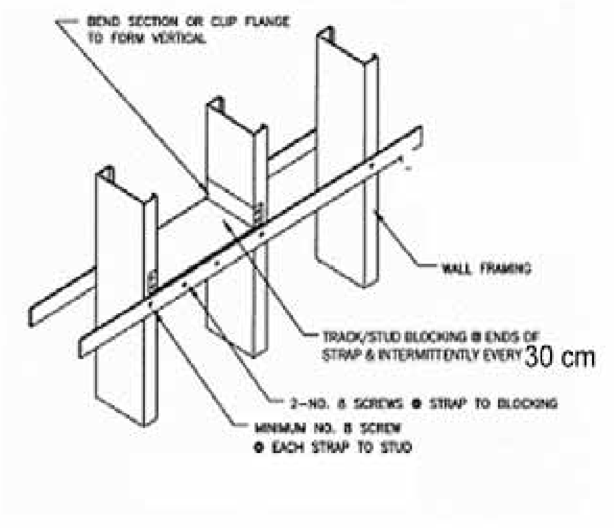


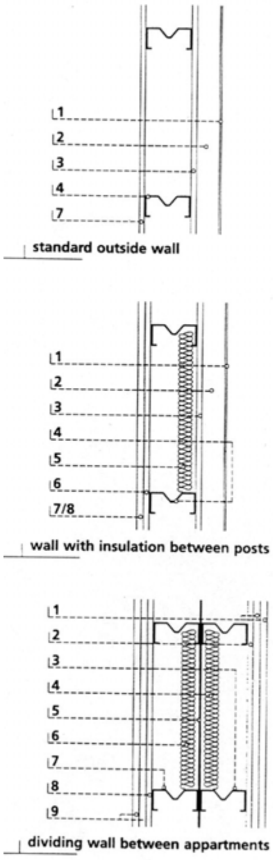
Figure 2.3 Stud bracing with sheeting material only

Figure 2.4 Stud bracing with strapping only

The profiles of the exterior (load-bearing) and interior wall elements may differ. Load- bearing walls should be placed along a line and should be supported by rafters or trusses. The load should directly be transferred from the below rafter to the foundation or to a load-bearing wall (or truss). Wind-braces should be added to the framing system at certain points in order to take the side loads (mostly wind loads). Fasteners and openings for the service elements should be designed in accordance with the given standards or experimented solutions.

1-Mineral plaster	5 mm	6- Extra steel section	30 mm
2-Polystrole insulation	60 mm	7- Plaster board	18 mm
3-Micro-trapezoid board	12 mm	8- Extra steel section	30 mm
4-CFS section	120 mm	9- Plaster board, 2 layers	26 mm
5-Sound insulation layer	30 mm		

Durability timing under fire conditions



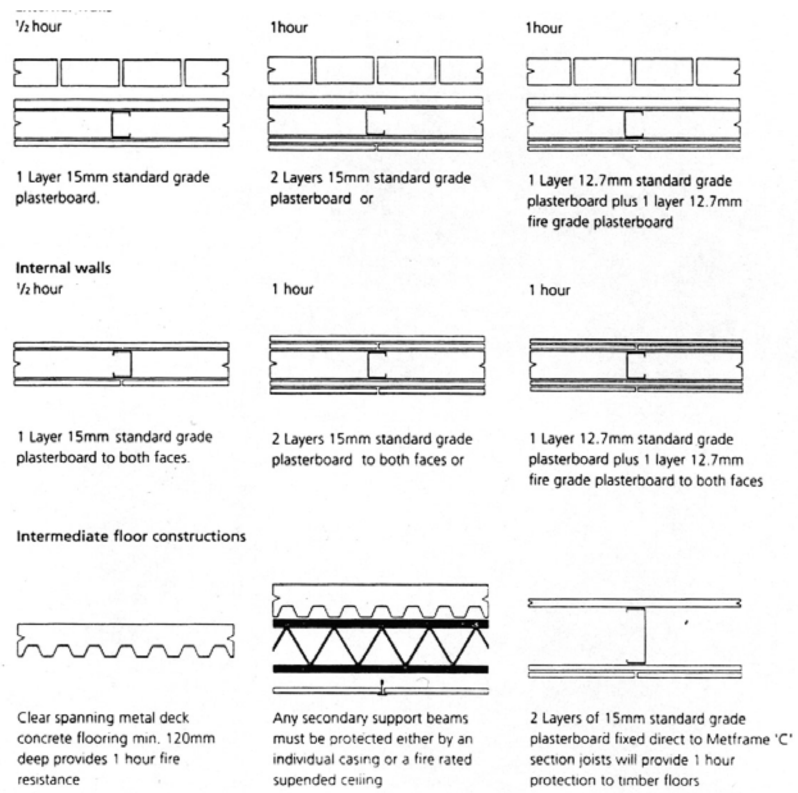


Figure 2.5 The different wall systems

Figure 2.6 The different wall systems' resistance timing under fire

For creating wall openings in the load-bearing walls, (all exterior and load-bearing interior walls) headers should be used. Headers shall be box-type profiles like the king studs that they've been fastened to. Jack, king and cripple studs shall be of the same dimension and thickness to the adjacent wall studs. Jack and king studs shall be interconnected with structural sheathing in accordance with Figure 2.7. Headers are not required for openings in interior non load-bearing walls.

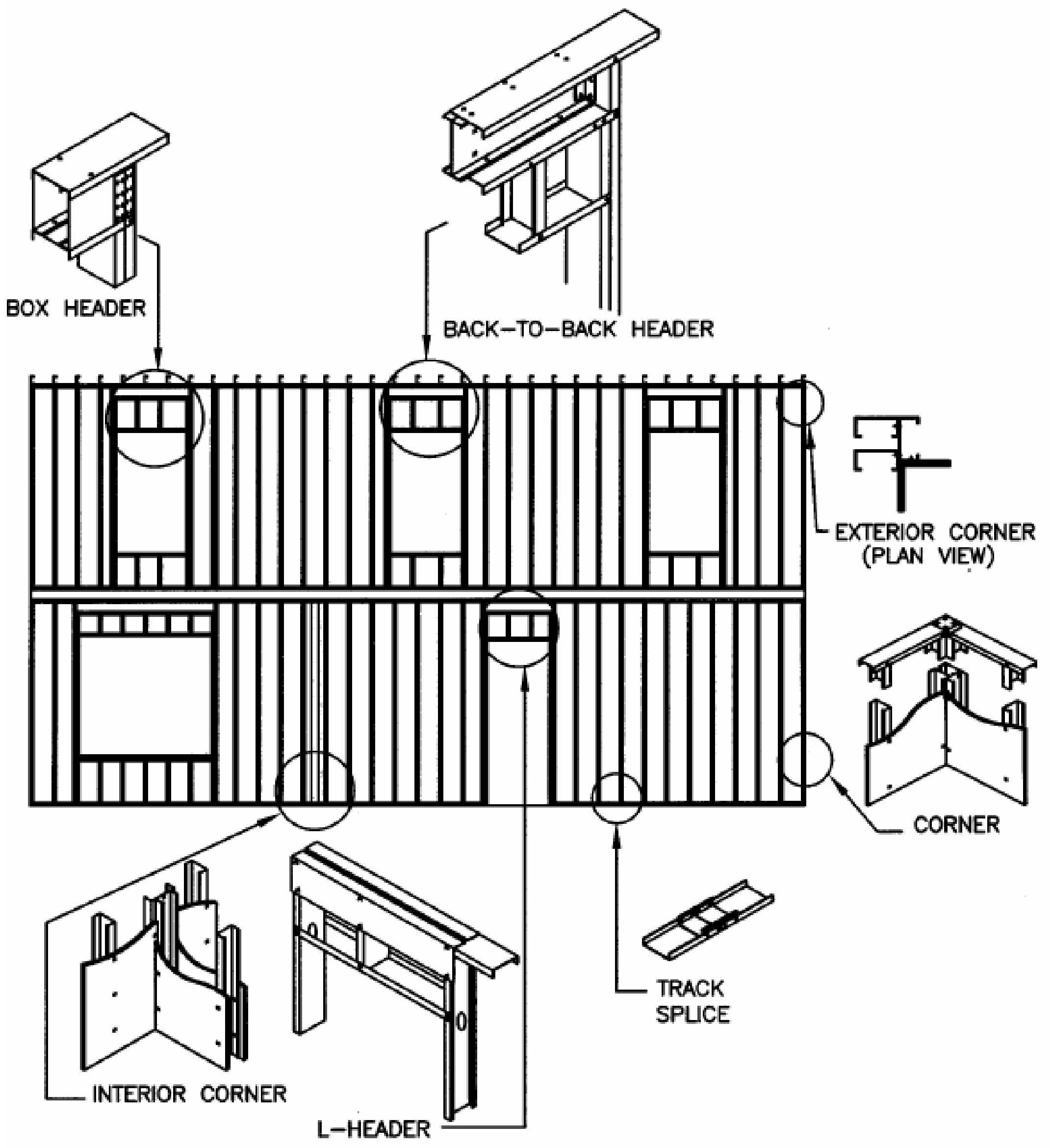


Figure 2.7 Wall system details

2.3.2.2.2. The slab element

Load bearing steel floor and ceiling framing shall be constructed in-line with the vertical load-bearing members located below with a standard spacing. The vertical load bearing main elements are held together by horizontal profiles (the steel strapping) attached in between and again the gypsum board is attached to the flanges by the help of fasteners that helps the floor to act as a whole element under loading and the gypsum board takes some load impact itself. The load calculated to be on the floor, governs the thickness, shape and the standard distance in between. Openings needed in floors should be framed by header and trimmer joists. All members around floor openings are required to be box-type members.

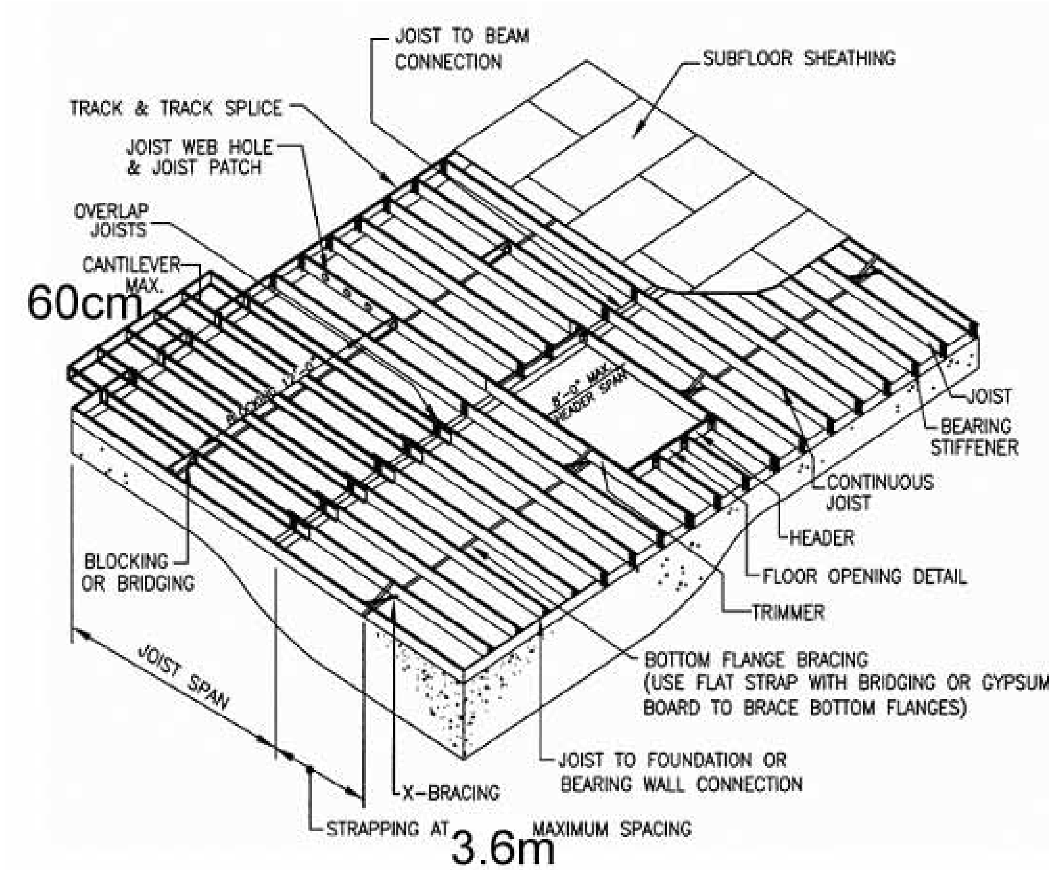


Figure 2.8 Slab system details

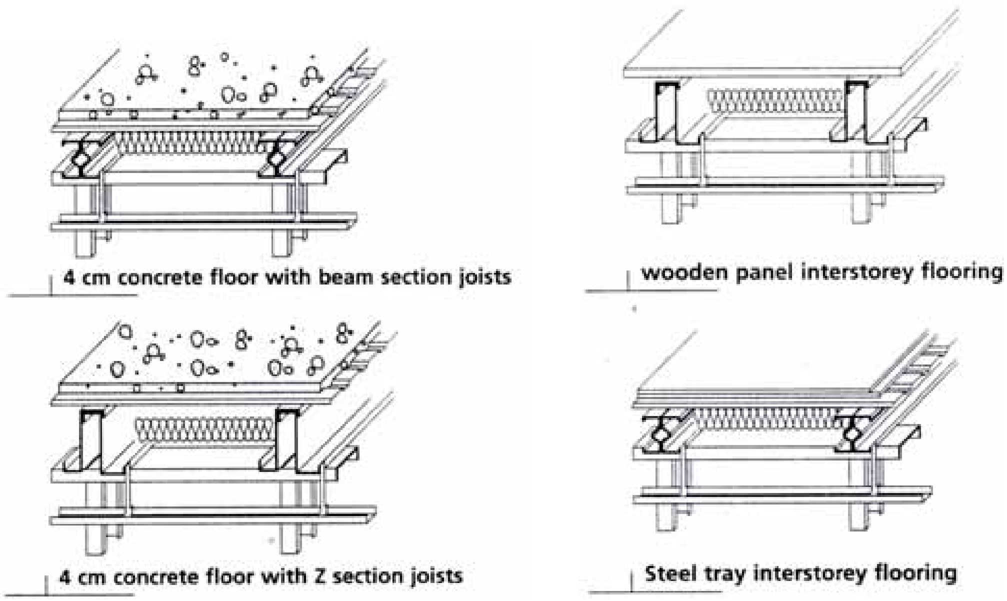


Figure 2.9 Floor system details for second floors

2.3.2.2.3. The base elements

The base (foundation) elements of LGSF systems must continue all under the load-bearing wall elements. In most of the systems to reduce the cost of mould, the base element can be used as concrete foundation raft. The anchor bolts must be used in order to fasten the track elements (the rafters) or the wall stud elements to the foundation elements.

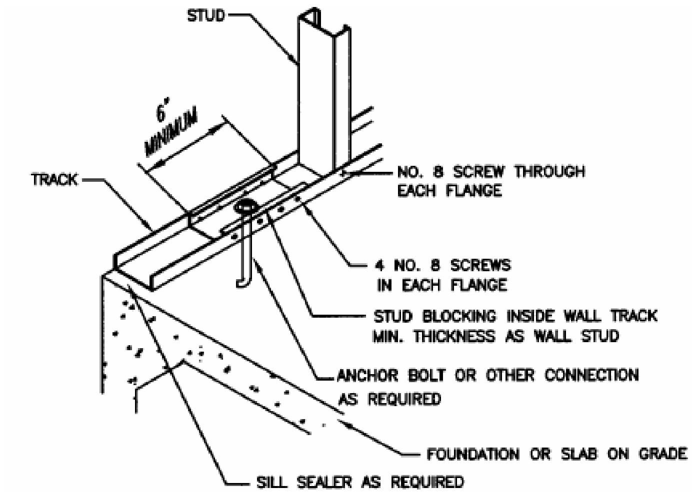


Figure 2.10 Wall to foundation Connection

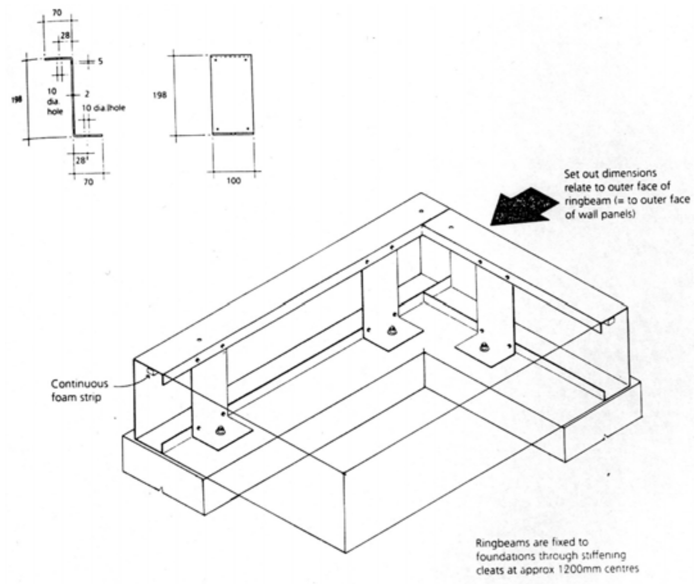


Figure 2.11 Connection of CFS profiles to concrete basement

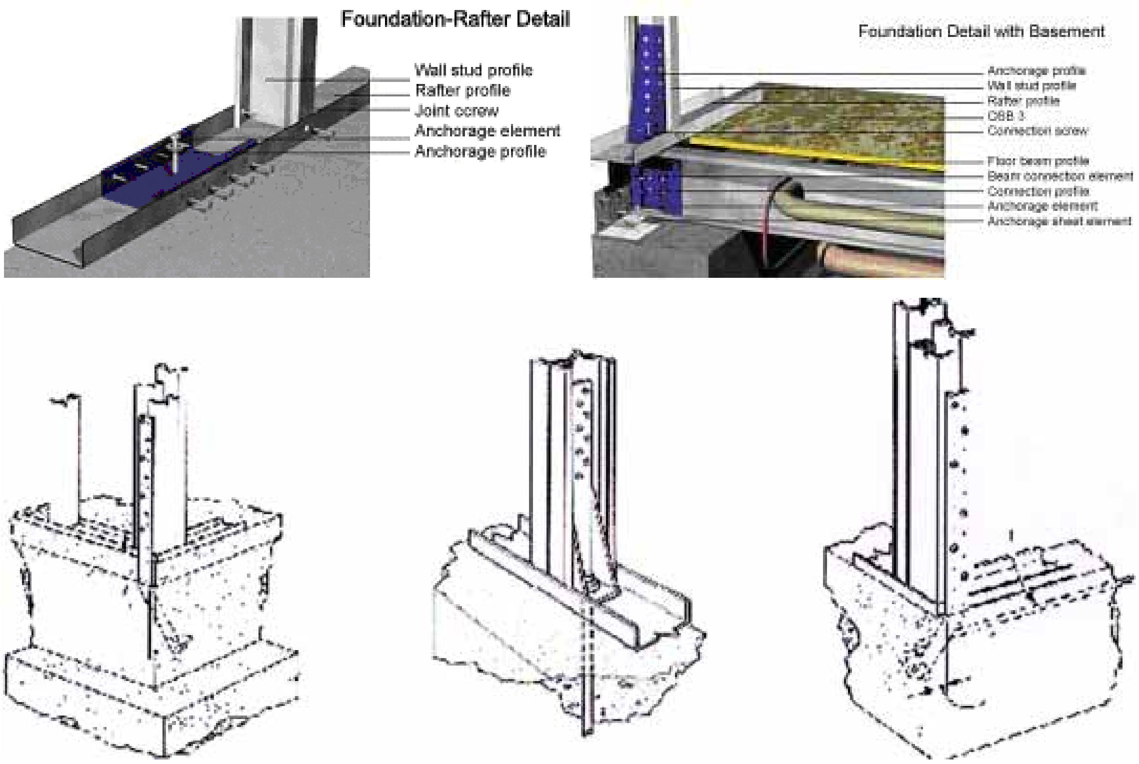


Figure 2.12 Various foundation details

2.3.2.2.4. The roof elements

Ceiling joists shall be located directly in-line with (on top of the) load bearing stud below with a maximum tolerance of 19mm between the centerlines of the stud and the ceiling joist. Fastening elements should be used according to the given standards.

The transportation of the roof frames may be harder than the wall panels, so the stick-built method can be used for fixing the roof to avoid such handicaps.

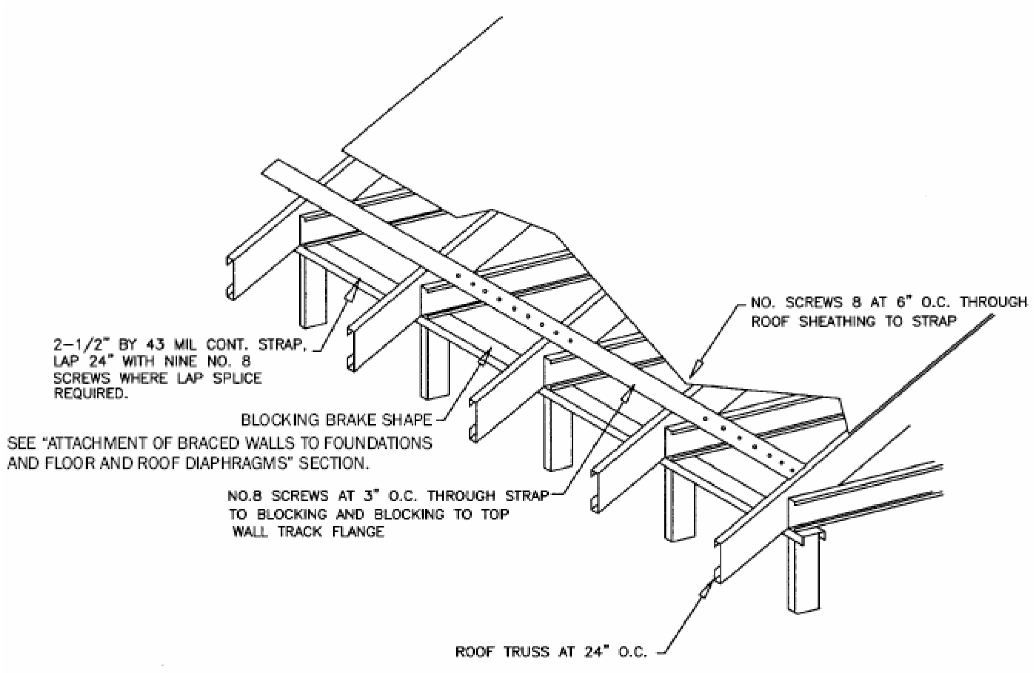


Figure 2.13 Roof details

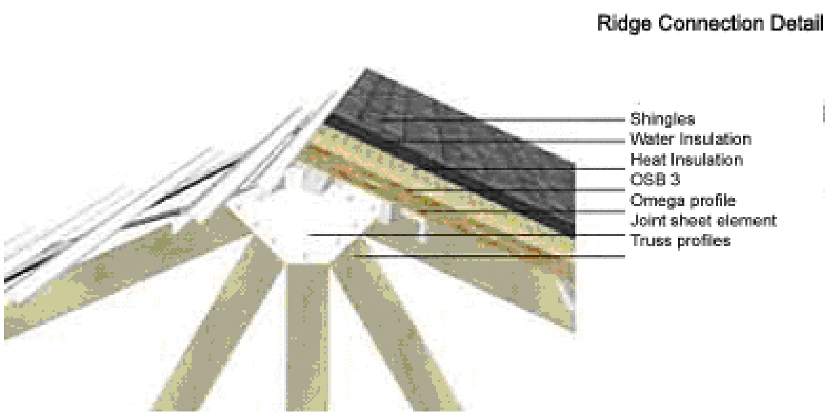


Figure 2.14 Ridge connection detail

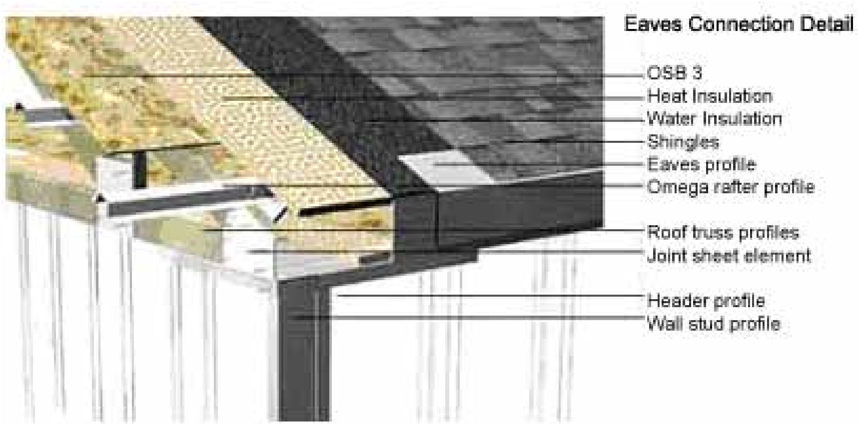


Figure 2.15 Eaves connection detail

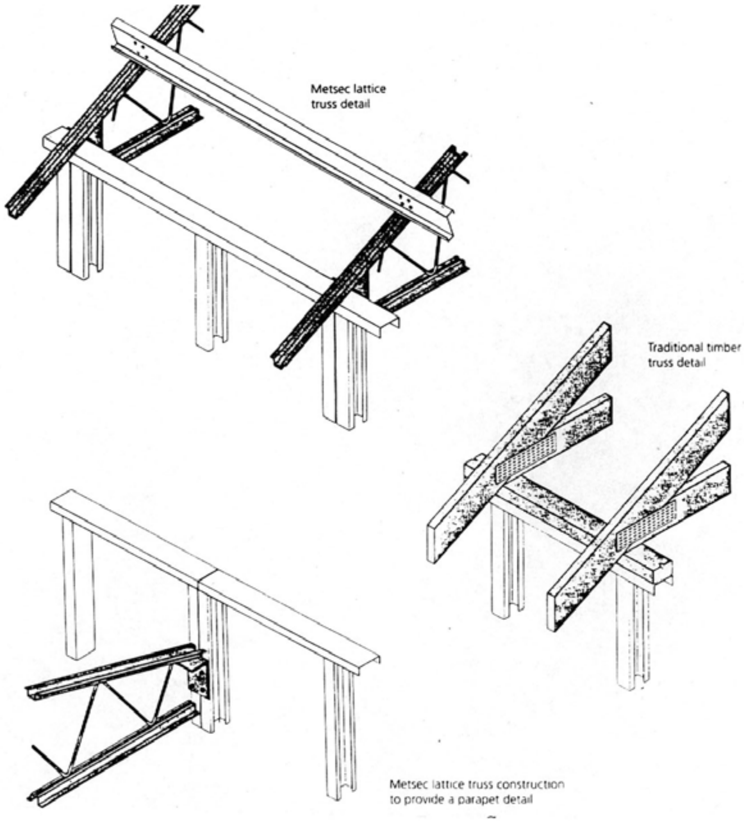


Figure 2.16 Roof truss-header connection details

2.3.2.2.5. The joint elements

Various joining methods are available for lightweight steel structures. The general types of joints in between cold formed steel main elements, in between profiles and in between sheathing elements and structure are made by:

-Welding
-Bolts
-Self-tapping screws
-Blind rivets
-Powder actuated pins

The detailed information on joint elements and methods can be followed from the appendix.

(See appendix C for details)

The structural joint elements in between light gauge steel profiles are hot-formed steel elements in various shapes shown below.

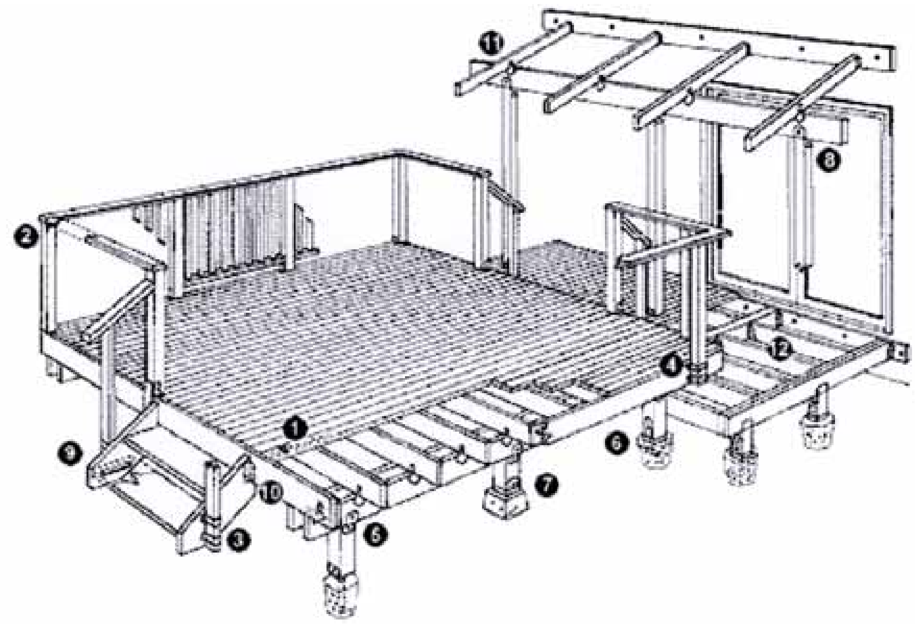


Figure 2.17 An example for light gauge system, wood frame structure and connections

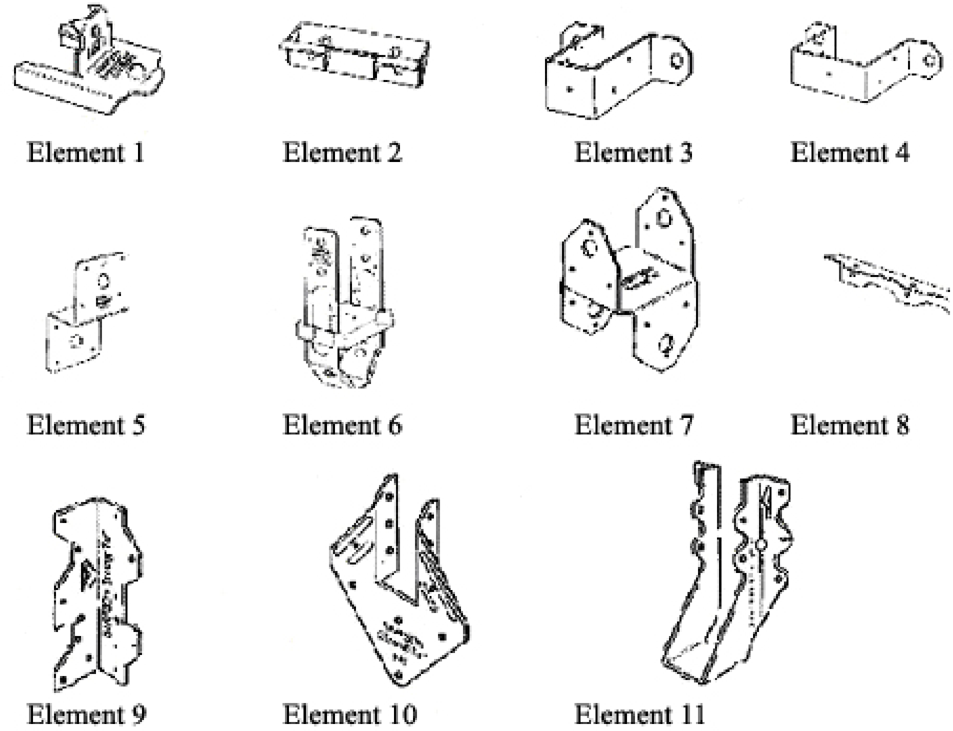


Figure 2.18 Hot formed steel connection elements used in light gauge steel systems

2.3.2.2.6. The insulation elements

The insulation elements of the system have extra importance for obtaining the standard comfort conditions of a standard residential building. The structural system elements should be insulated from the outdoor conditions in order to maintain the durability of the system. Vibration, sound, fire and moisture protection are the main factors that the system should be protected from.

The insulation elements may vary, but mostly gypsum board, mineral wool, cellulose and rigid foam insulating products are preferred, because they do not react with galvanized steel.

The detailed information on insulation elements and methods can be followed from the appendix.

(See appendix D for details).

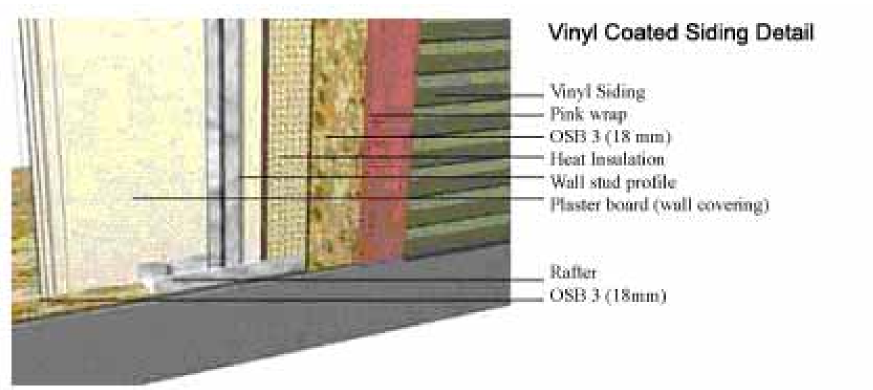


Figure 2.19 Vinyl coated siding detail

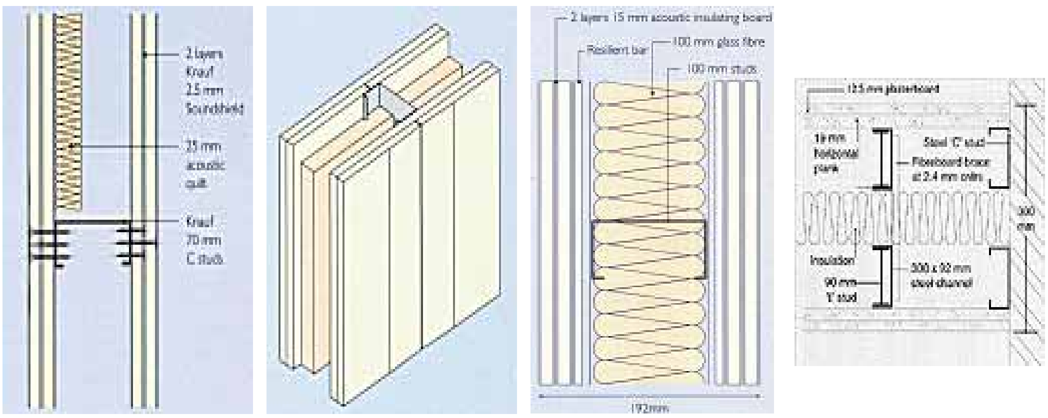


Figure 2.20 Sound insulation with glass wool

2.3.2.2.7. The covering elements

All kinds of covering elements can be used for the exterior finishing of the LGSF system, but it should be considered that fresh mortar and plaster may do harm to zinc and zinc alloy coating when they damp before the material is dry. For covering the cold formed steel (CFS) structural elements with materials needing mortar and plaster necessitates a dry board in between to avoid the reactions.

This board is mostly chosen as the gypsum board, OSB or plywood board, which also helps the wall system to be stable. Elements attached to the structural elements carry the outside covering. (Figure 2.3)

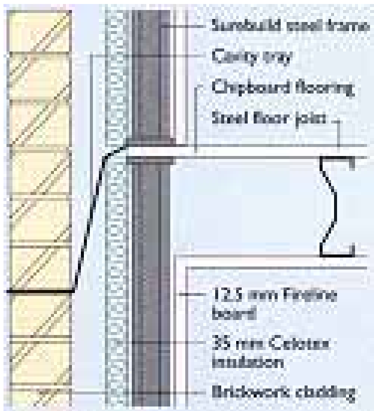


Figure 2.21 Section detail of brick wall system attachment to LGSF system

In order to keep the system light in weight in accordance with its structural web system, only insulation elements and plaster boards can be used over the gypsum board level. This is the general system used for mass produced systems. (Figure 2.5)

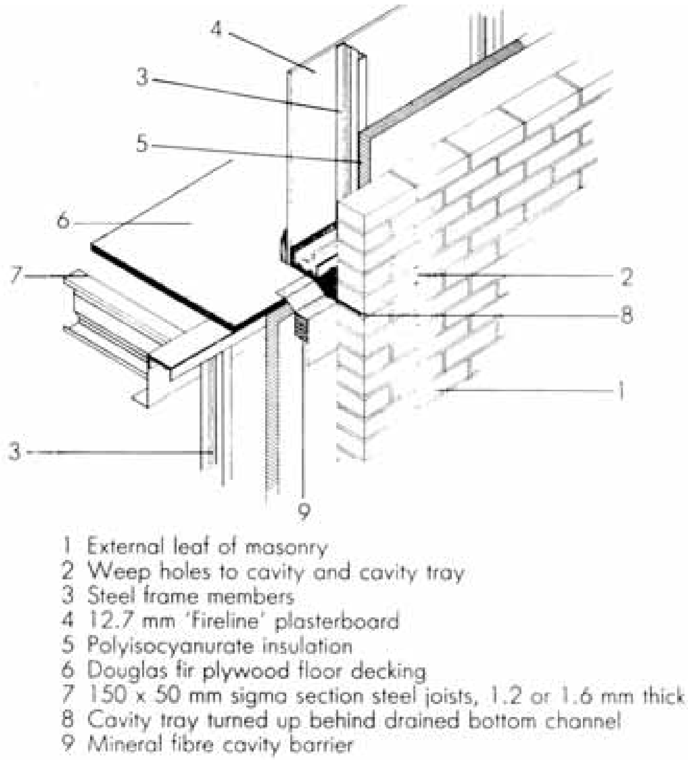


Figure 2.22 External wall detail of "*Surebuild Construction System"*

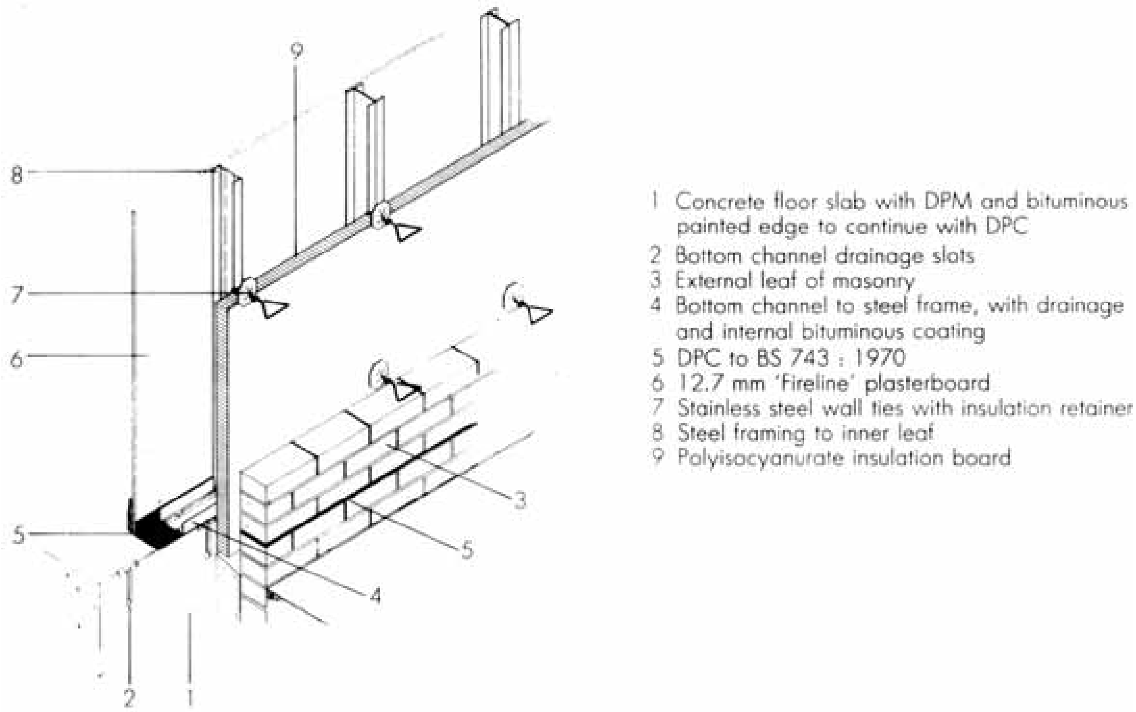


Figure 2.23 External wall detail of *"Surebuild Construction System"*

Metallic coated steel does not react with dry wood. No special requirements are needed to fasten the steel to the wood. Galvanized nails and screws are successfully used to join them. Also glass can be adapted to the framing system as a cladding system. It can be hung on the system facing outside, yet the gypsum boards or insulation elements cannot be adapted to the glass parts in this case. Thermal problems should be solved by other methods in this case and the framing system profiles should be chosen from lower gauged thick profiles in order to keep them stable by steel strapping and bracing without different elements.

Different residential example coverings in the third chapter will help to understand about different covering techniques, better.

2.3.3. The Production & Construction Steps of LGSF

The production and construction steps of the LGSF system are different than the other construction methods. It is likely to the prefabricated concrete system at some points; but this system is much faster to apply and in this system every detail of the system has to be pre-designed in order to build the basic LGSF system. In this construction process there's no tolerance for any mistakes which makes this system important for Turkey in a way.

2.3.3.1. Design Process

The timing in the design process is an ambiguous issue. The designer and the owner have to decide together on the project of the house, which can even take years; but here the mentioned design process is the process after this step. The constructional design process of the house, which only takes a few days with computer work (STRUCAD or AUTOCAD program) with the standardized construction details of the factory chosen. Autocad or other design programs are available for the Cad work and Strucad software program contains the production detailing and CNC manufacturing information for the CFS profiles. There are other design programs, which have been developed in order to obtain the most appropriate section for a given span and loading configuration. Most of the design programs are derived according to British Standard

BS 5950. The constructional design process depends mostly on the economic utilization of the structural elements, for keeping a minimum cost for a project, mass production and relevant dimension choice should be done to obtain these.

2.3.3.2. Production (Factory) Process

After the whole design process is finished, the cold formed steel profile designs are transferred to CNC machines in order to form the exact profiles for the building by rolling machines in the factory. Adjustable rolls are often used which permit a rapid change of section depth or width. Usually, set up costs are high if special rolls are needed or repositioned. The lengths of the members can be programmed and cut automatically. Maximum cut lengths are usually between 6 and 12 m. Holes for the attachments of technical units can be punched before or after forming. Other alternative method of forming is by press braking. Normally this method is practicable for short (up to 6m.) and simple element cut, however because of its low setting up costs this method can be more useful for small quantities of production. (Rhodes, Lawson, 1992)

In the factory process, the standard cold-formed steel profile utilization usually minimizes the production costs and time, because the roller adjustment wouldn't be required in this case. Other materials such as board elements, covering elements are maintained and prepared to be installed in the factories as well. The integration of the other components in the system like the panel elements, insulation layers or technical units can be made in or out of the factory according to the construction method.

In the modular system all units are prepared in the factory in some cases, even the technical equipments of the bathrooms may be placed in the factory. In modular system the site construction is very fast (one day is enough in some cases). In the panelized system which is the system used in our country, the structural wall panels (the sub-frames) and other components are prepared in the factory and bind together at the worksite. All these elements production for a single or double storey house process only takes a week in the factory. The panels can be prepared with all the other covering and insulation, even with the technical pipes in the factory in some cases. Also in stick-built system all single elements are prepared in the factory but because all connections and integrations of this system are done at the worksite. Factory process of this method is even shorter than the panelized method. The stick-built elements are long elements, which are hard to be transported, this fact is a handicap for this method to be used.

2.3.3.3. Construction Process

The construction process which contains the transportation of the products to the building area and their montage, takes at most a week with only a few workmen for a single family house for panelized LGSF methods. Stick-built construction method takes four times the time of a panelized LGSF house construction at site. Yet, this is a very short time for construction as well, which is an advantage of this system. Also construction time isn't effected much by the weather conditions like the traditional concrete system used in Turkey. The construction of modular system LGSF units at worksite takes only a day or two, but this construction method requires work machines like cranes and big trucks and as mentioned above the factory process is longer. In this method weather conditions at the worksite has no affect on the construction process.

Even though the LGSF system elements are taken to the building site ready to be constructed in all methods of construction; the construction process needs extra care in this system. The connections should be done right in order to maintain the physical strength of the system; so the qualified workmanship and special construction elements are needed for this LGSF construction. Yet the system is so light in weight that it is possible to build a one-two storey house with only 3-4 workmen. As said before the construction of such a house takes only a few weeks for 3 qualified workmen which means an important cost release in workmanship compared to traditional construction systems.

2.3.3.3.1. The different construction methods of LGSF

The three basic residential steel framing assembly methods are;

- Stick-built construction
- Panelized systems
- Pre-engineered (modular) systems

a) Stick-built construction

Wood and steel stick-built construction are similar. The steel materials are delivered to the building site in stock lengths or, in some cases, are pre-cut to length. The layout and assembly of steel framing is the same as wood framing except that the components are bolted, or screwed with self-dripping, self-tapping screws together rather than nailed. In “balloon” construction, the wall elements are vertically continuous, and the floors are attached to the side of them, as in normal beam and column construction. Steel joists can be prefabricated in long lengths to pass the full width of the house with a single one. This expedites the framing process and eliminates the lap joints. Framing members are typically spaced at 40 or 60 centimeters on center. The studs and joists are sized by thickness and depth to handle the expected live and dead loads. Sheathing and finish materials are fastened with screws or pneumatic pins.

This elemental or “stick” approach is more flexible, as it can accommodate variations on site (Figure2.24, Figure 2.25). However, it requires fixing and possibly cutting of members on site, which causes the system to be slower than the prefabricated one. The floor members may also be designed compositely with a concrete slab in order to ensure that the two materials work together.

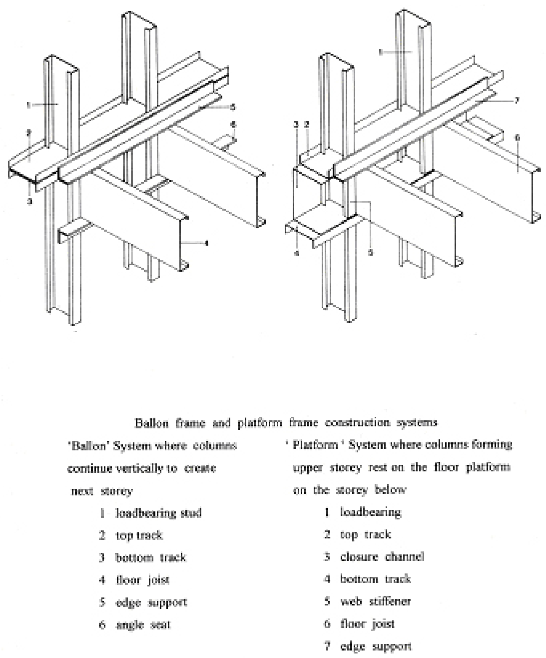


Figure 2.24 Balloon frame construction

Figure 2.25 Platform frame construction

b) Panelized systems

Panel systems consist of a system for pre-fabricating walls, floors and/or roof components. This method of construction is most efficient where there is a repetition of panel types and dimensions.

Panel systems are mostly fabricated in the factory or in the field. A jig is developed for each type of panel. Cut-to-length steel members are ordered for most panel work, placed in the jig, and fastened by screws or welding. If exterior sheathing element for each panel is specified, it may be applied to the structural panel prior to erection. The panels are then transported from the atelier to the jobsite. On site these panels or sub-frames are either manhandled in small units or more commonly lifted to the place by the help of a crane, so the labor is only required to line and level the panels and make the necessary connections in between the panels. Whether or not a panelized wall system is used, steel trusses for the roofs are usually prefabricated this way.

Factory made panels can offer several significant advantages to the builder. The panel factory provides a controlled environment where work can be preceded. The weather conditions do not have any effect on fixing process. Application of sheathing and finishing systems is easier and faster with the panels in a horizontal position. Although the panels must be transported from the panel shop to the job site, the cost advantages of panelized systems most often offset the added transportation costs.

Panels can also be made up on site and used in either “platform” or “balloon” construction methods. “Platform” construction involves placing wall elements on floors, so that compressive forces are transferred through the floor elements. Platform construction is most widely used for houses and low-rise buildings.

c) Modular (Pre-engineered) systems

High strength and design flexibility of the steel material makes innovative systems possible. Pre-engineered systems typically space the primary load carrying members more than 60 centimeters on center, sometimes up to 2.5 meters. These systems use either secondary horizontal members to distribute wind loads to the columns or lighter-weight steel in-fill studs between the columns, they are not usually load bearing and generally supported by the floor slab. Furring channels used to support sheathing materials also provide a break in the heat flow path to the exterior, which increases thermal efficiency. These prefabricated units take the generic name "module" and are often designed to be re-locatable. Many of the pre-engineered systems provide precut-to-length framing members with holes predrilled for bolts or screws. (NAHB Research Center, 1994)

2.3.4. The Protection and Maintenance of the LGSF Building

The LGSF system has to be protected in some manners. The protection should contain the protection of the biological, ecological and physical conditions of the building system and also the health of the living creatures inside with the help of some accurate detail organizations.

2.3.4.1. Biological Protection

The biological property of the LGSF system, which is designed by the combination of some plastic based industrial materials, should be discovered and observed. The biological occasions in the building directly affects the life of the building; also the system details cause the building to act as a non breathing cell; the health conditions for the living creatures in such a building should be analyzed. There is no study found on this subject.

2.3.4.2. Ecological Protection

"*The ecological protection in the building industry can be held by "to reuse the same material" or "to recycle the old material for reuse*". (Işık, 2000)

For structural steel building elements, it is possible to reuse the main structural elements with or without recycling, but for light weight steel elements that are put together in the building site (stick-built method) to fix them apart and reuse them in the same way is hard, because mostly in length the stud elements are the same with the house and breaking the system apart have big difficulties. For panel elements that are built in the factory with lightweight steel structures and without welding, it is possible to dismantle and reuse the same panel elements in another building system. Welding causes problems in the reuse of steel structural members. Lightweight steel elements also can be melted for reshaping and they can be used in any other production.

All types of steels can be recycled with no lost. % 50 of the steel mine used in the production sector is recycled material and the other % 50 is from new mine. In Turkey 25% of steel used in LGSF structures is maintained from recycled steel. If the energy and water usage and the out coming solid and gas wastes are regarded, steel (and light weight steel) seems to be best material in the ecological concept among the other construction materials.

2.3.4.3. Physical Protection

As lightweight steel material is produced from thin steel sheet element, it shows the same properties with the structural steel elements. Like structural steel, lightweight steel profiles are affected by fire and corrosion. The cold-formed steel profiles should be covered with thick enough fire protection layers. The fact that LGSF buildings are possible to be built up to four storey systems and the cold-formed steel profiles are incombustible help people to leave the LGSF building very fast in emergency occasions, and this is a benefit of the LGSF system.

Also corrosion protection has great importance for the long last of this system. The thin sheet material is much more affected of humidity compared to hot-rolled structural profiles. The general maintenance period of LGSF buildings range from 60 to 100 years according to the different international company data.

2.3.4.3.1. Fire Protection

The profiles of lightweight steel buildings should be protected from fire, because of their thin sheet material structure. Protection from fire starts in the design process. At temperatures higher than 450 °C the steel looses its load bearing strength by the effect of lengthening, in light gauge steel this critical temperature may decrease to 160 °C. In order to keep heat affects away from the structural system, over coating systems should be applied (Figure 2.6). The materials used for the over coating system should be chosen by considering their fume and poisonous gas potential in fire occasions. For indoor covering element plasterboard can be a protection element for fire, but the outdoor covering & insulation needs to be chosen with extra care to avoid heat bridges in the LGSF system. Essentially, the effect that -galvanized steel profiles cause poisonous gas in fire- shouldn't be forgotten.

The Light Gauge Steel Framing System is a system that can mostly be used in single or double storey buildings at the moment. In case of emergency, it is very easy to get out of such a building, so it can be said that the most important precaution is to leave the building in fire occasions as soon as possible.

2.3.4.3.2. Corrosion Protection

Corrosion is extremely dangerous for structural steel. Corrosion can be threatening in regions where relative moisture is over 60%; in agricultural sites, industrial areas and seaside. For protecting steel from corrosion, these precautions can be done;

Protection by painting: After cleaning the surface of steel by chemical or physical techniques, covering the surface with zinc or lead based paste or bituminous paint.

Protection by galvanizing: After cleaning the surface of steel, galvanizing chemically or physically (by plunging in the galvanize solution).

Protection by alloys: The alloy steel that specially contains copper makes an oxidation layer over the surface, which protects the material from corrosion.

Because of the section of cold worked steel elements are thin; they are effected by corrosion more. For the protection of steel sheet element, which is used for rolling the cold-formed profiles, usually physical galvanizing technique is used. Galvanic zinc coating (galvanizing) is the most common way of protection. This process is done in the factory, so standard quality is reached. A coating of 275 g/m^2(total on both faces) is satisfactory for internal environments and corresponds to a total zinc thickness of about 0.04mm. The thicker coatings are used in applications where moisture may be present over a long period. (Figure 2.26) Galvanized steel has good durability because, unlike paint, scratches do not initiate local corrosion of steel. After the fixing of the elements, the parts that galvanize layer is removed should be repaired. The expected design life of galvanized products exceeds 60 years (Rhodes, Lawson, 1992; Tezcan, 1995). Also the corrosion effect should be defined well.

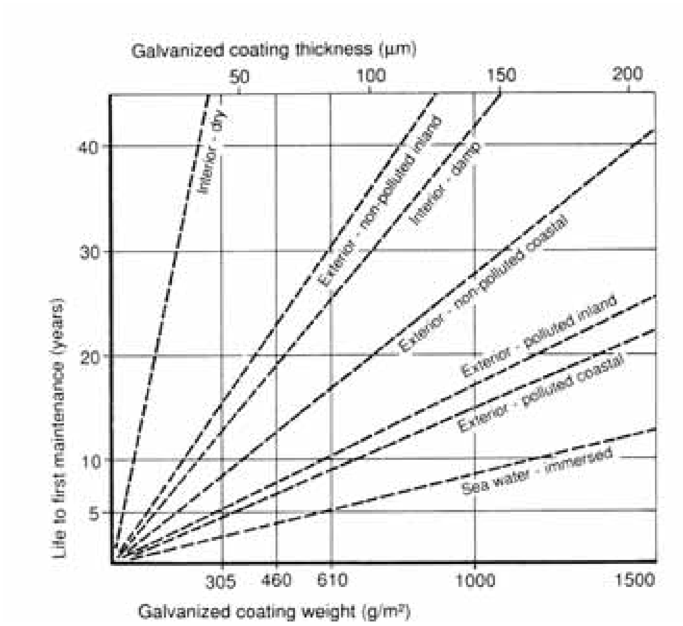


Figure 2.26 Relationship between life of zinc coating and is thickness

As a precaution of corrosion, in the wall and slab sections condensation should be prevented. The heat and vapor insulation layers of the building should be calculated well and also for moisture removing, some air circulation space should be left in between the layers.

CHAPTER 3

LIGHT GAUGE STEEL FRAMING SYSTEM EXAMPLES

3.1. A General Overview on the LGSF Housing Stock of the World

LGSF housing system is a system that permits a construction up to 4 storey buildings (maximum) without the support of any other structural construction material. This may be a disadvantage for some countries in the world like Turkey. In Turkey, residential buildings are planned as 5-8 storey, even higher in the city centers where land costs are fairly high.

World's residential building traditions should be analyzed in order to see the parallel improvement of the LGSF houses around the world.

In the history section of the previous chapter, it had been declared that the general development of steel houses in the world had started with the industrial revolution and the increase in the utilization of steel in the housing sector showed itself after the two World Wars. LGSF system had been an alternative for Japan after World War II with the restriction of wooden framing. After the Second World War, other than some experimental examples of lightweight steel houses in Germany, no other examples of LGSF construction can be seen through Europe until the last 10 years. In the last ten years starting with UK, LGSF system in residential construction is spreading around Europe too. Although the technology of this new system had been discovered, Europe is the slow moving region in the utilization of this new construction system compared to other parts of the world. This is parallel to the European housing tradition. The city planning which is mostly defined by the old city center limits the land-usage through Europe and because of this; *"Cost-effective utilization of the expensive property in cities led to widespread construction of apartment buildings."* (Schneider, Friederike, 1994).

This high-rise housing tradition is still dominant in many countries in Europe. Only UK may be excluded at this point where many of the residential housing stock still consists of 2-3 storey apartments and row-houses even in the main cities.

"Several of the UK Top 20 house builders are now using steel frame for flats and two-story homes. Some companies are now specifying steel in production quantities, while others are involved in pilot projects to compare light steel frame with other innovative construction techniques. Faced with a shortage of skilled labor and increased demands for quality from customers, the industry has recognized that it must move towards shorter construction times, more efficient design and increased industrial production of steel homes or metal homes. Steel is one of the most effective ways to meet these objectives." (http://www.studchopper.com/index./Steel Homes, Metal Homes history.html)

Today, mostly in the city center residential areas of UK, LGSF modular systems are constructed with structural steel connection elements in order to maintain the 5-6 storey new residential buildings. In the multi-storey examples chosen from UK, the high quality of modular LGSF system method of the building companies will be shown.

In some other countries of Europe that has studies on LGSF system like Denmark and Sweden, these studies focus on the opportunities of the utilization of LGSF system in multi-storey buildings. Still there are examples of 2-4 storeys LGSF constructed fast-built building examples exist in Europe. In France and in the Northern European countries, LGSF system is mostly used in ski centers for maintaining fast and easy ski resorts.

In America, Canada and Australia following the building tradition, the LGSF system had a big place in the construction market of today. Today 20% of the housing constructions in U.S.A. are made with LGSF system. America and Australia continents are the last discoveries of the world, so the historical entities of these countries are not as rich as Europe or Asia. The land-use policies of these places are also different. America had always been a place where transportation had great importance that planning mostly depends on the highway system and it's a place that still has a lot of spare land. The planning paradigms of America and Australia are different than Europe's and in these places planning criteria separate the residential areas creating a low-dense residential living. However in Europe or in our country, apartment buildings are constructed creating high-dense residential areas especially in the centrums.

In America, it's easy to say that the building sector is a market where standard houses are designed and built all around, so the unique design works aren't much in progress. As explained before, the LGSF system is an alternative system to wooden frame systems for the continuity of the residential tradition and now it has a big part in the housing market of USA (where 1-2 storey houses are built). Like the wooden frame house sales, the LGSF systems have been sold from already made catalogues and projects. There are even, "Build your own House" package houses for sale. In Canada and in Australia with the similar housing tradition, the standard house package sales are popular, too. The fact that can't be regarded is -the most feasible and economical way of producing and selling LGSF houses is mass-produced pre-projected package sales.

In Turkey, as a country which has the LGSF housing system for five years, the market follows the most economic way, by producing standard profiles and housing packages where as the single family house is mostly a high cost type of residential development for Turkey. If the LGSF system buyers want the exact home they wish, this forces the producers to design extra details and system components, but mostly the producers ask the designers to build in the limited dimension data of the producer company, like building the wall studs to be placed in 60 cm distant. The approximate dimensions specified for the LGSF house design in American standards are the dimensions of a typical traditional wooden house construction. The profiles produced following the American market are forcing Turkish profile producers to design constructions like American wooden model. In the examples we will follow the similarities of the Turkish and American LGSF houses.

Turkey is the place of experimental works on LGSF at the moment following the American marketing model.

3.2. House Examples from the World (with LGSF system)

3.2.1. A Classification of All Residential Examples in the World Constructed with LGSF System

There are three methods of constructing Light Gauge Steel Framed houses as explained in the second chapter in detail and the various interesting residential examples from the world are given according to their different construction methods in the following section.

3.2.1.1. Stick-build LGSF Examples

1- A Three-Storey Apartment Block in Light Steel Framing

Architect	
Contractor	Fairview New Homes Ltd.
Steel frame suppliers	Speedframe Ltd.
Framing components supplier	Ward Building Products Ltd.
Location	Chequer's Way, Palmers Green, U.K.
Date	1997
Number of storey	3
Area	
Structural system	LGSF with stick-built system
Connection Elements	Bolts (moment-resisting) and Self-tapping screws for minor elements
Outdoor coating material	Brick
Construction time	4 days

Photo 3.1 A Three-Storey Apartment Block in Light Steel Framing

Design Features

This project at Chequer's Way, Palmers Green, is one of the first multi-storey residential blocks to be constructed using light steel framing, and extends the current use of steel framing from two-storey houses into the higher-rise residential sector.

"Identical external appearance allows mixed developments of steel-framed and traditionally-built homes," the company of UK says. For UK, to keep the traditional residential housing style is a very important issue. This is the first three-storey apartment block to be built in light steel framing with the traditional look.

Structural Features

This system differs from other light gauge steel systems because it uses pre-formed sections, as opposed to pre-fabricated frames, which are bolted or screwed together on site.

Photo 3.2 Construction steps of "stick-built" method

This alternative method of building is suitable for taller or unusual shaped buildings because the section size can be selected to suit the loading or span requirements.

"Stick-built" means that it is particularly flexible. No crane work is required. The Multi channel sections are preformed and bolted together in the site, which does not disturb the galvanizing layer. Other components are fixed by means of self-tapping screws that create a gas-tight metal-to-metal joint. It is self-supporting and doesn't need support from diaphragm floors or internal walls.

Photo 3.3 The wind bracing elements used in the construction

The sizes of the sections depend on the application, but are typically 175 mm deep for floors, and 150 mm for load-bearing walls. The building is three-storey high, and incorporates a habitable roof space, thereby maximizes the useable floor area. The connections between the members are designed as moment-resisting ones, which eliminate bracing on the front and rear facades. The walls are insulated in the cavity and additional quilt is provided between the separating floors and walls to achieve good acoustic insulation. The wind bracing elements are holding the total wall elements as seen in Photo 3.3. Construction of the brickwork progressed quickly after partial completion of the framework. A special wall tie system has been developed which improves the speed of construction.

A light steel framework like this one can be erected and insulated in four days. (SCI, Case Studies, 2000)

3.2.1.2. Panel system LGSF Examples

1- Light Gauge Steel Studio

Architect	Tezuka Architects
Contractor	Nichinan-Tekkou
Location	Japan
Date	May 2001
Number of storey	3
Area	380.82m²
Structural system	LGSF system with cable wind braces
Connection Elements	Bolts
Outdoor coating material	Plexiglas
Construction time	

Photo 3.4 Night view of Light Gauge Steel Studio

This is the studio of the Tezuka Architects. Tezuka architects are a couple who studied architecture in UK. After working for Richard Rogers, they've chosen to return back to Tokyo and work in their own office.

Design Features

The studio is designed to be a place where daylight may reach the whole indoor spaces. It is a 3-storey building with a basement floor. The floors are designed to be total spaces with no columns or walls inside. Another interesting detail of this place is the floor openings, which also can be defined as atrium. These narrow and slim openings may be opened or closed according to the needs of the moment. The night look has been designed with the structural system. The ventilation system of the building has been worked in detail because as it can be seen that almost no windows are used in the design of this building. The air conditioning system elements are attached to the ceiling structural elements like in the examples of steel structural systems.

Structural Features

Photo 3.5 The Structure of the Studio in the main façade

The structural system of this building is light gauge steel framing. The cold-formed steel profiles were chosen from thicker sections in order to maintain the approximate 100m² open space in each floor. The wind-bracing elements, which are needed in the seismic zones like Japan, are chosen as cable steel elements. These cable elements had been distributed according to loading values as more in the second floor, which takes the load of the elements in the third floor and isn't been carried by a structural wall under. The main façade has been covered with Plexiglas cladding system that also keeps the structural elements away from the outdoor conditions. The other three façades have been covered mostly with trapezoid metal material and painted in white; only some narrow windows are made of Plexiglas in this building.

The system is different from the other LGSF examples with its structural simplicity, no board elements (gypsum, OSB or plywood) are used to integrate the wall components or for protecting them from fire. Also no extra insulation elements are used in order to avoid vibration or humidity, so the structural system elements are visible under the transparent coating elements. The fire protection and air conditioning problems have been solved by equipments and machines attached to the structural system. It should be mentioned at this point that plexiglas is a plastic based material that avoids the heat transfer, which especially increases with CFS profiles.

Photo 3.6 The inside of the building, the atrium

The basement has been designed with concrete structural wall (also foundation element) carrying the main structural LGSF frame, which is an intelligent detail.

Photo 3.7 The Ventilation system details

Photo 3.8 The basement

Photo 3.9 The opening atrium detail

Tezuka architects have been working with LGSF system in other projects as well. They've won 2 prizes with their designs up until now and have future design ideas to be constructed with the same system. Some examples are shown in the photos below.

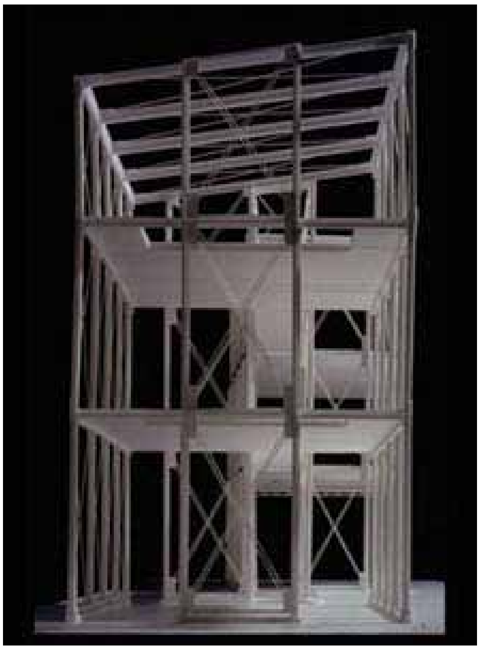



Photo 3.10 Night view of LGS Building

Photo 3.11 The structure

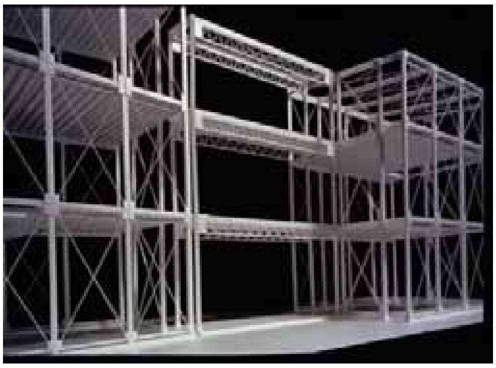



Photo 3.12 Other Project Component Systems

Photo 3.13 The Foundation System

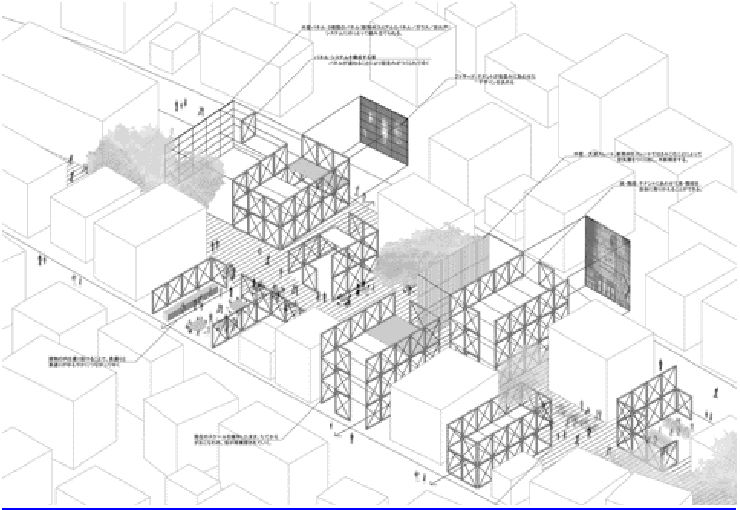


Figure 3.1 Proposals designed with LGSF system for the site

The Thin Walled House

Photo 3.14 The thin walled house

Photo 3.15 The outside view

Photo 3.16 The interior views

The Light Gauge Steel House

Photo 3.17 The LGS house

Photo 3.18 Balcony perspective

Photo 3.19 The interior look (http://www.tezuka-arch.com/japanese/works/html)

2- An Architect's Riverside House in Light Steel

Architect	Adrian James Architects
Contractor	Robert Gee, Cumnor, Oxon
Structural engineer (foundation)	Ian Howdill & Associates
Steel frame suppliers	Metsec Framing Ltd, A division of Metsec plc.
Location	Oxford, UK
Date	2001
Number of storey	3
Area	
Structural system	LGSF with panel system construction method and hot rolled steel elements
Connection Elements	Bolts
Outdoor coating material	Brick
Construction time	5 days

Photo 3.20 An Architect's Riverside House in Light Steel

Design Features

The house has won praise for its elegance and its contribution to the townscape. Its significance is great in view of the fact that it was completed by a small local builder with no previous experience of light steel construction. This house had won the Best Single House Brick Award in 2000.

The three-storey structure of the house was constructed in just five days. The structural frame is a combination of hot rolled and light steel elements. The hot rolled sections created a clear bay facade, while the light steel joists led to a totally open ground floor and a huge bay window opening on to the river. The light steel framework is concealed within the brick cladding, but the hot rolled sections are brightly highlighted (red painted) on the exterior. The bay window has a highly visible steel frame externally. The open roof space is occupied as a bedroom, thereby maximizing useable floor area.

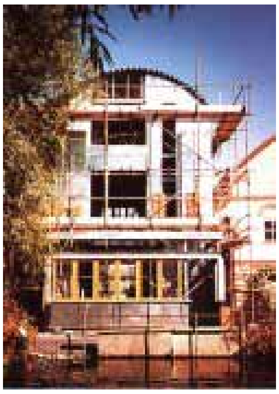
"Light steel" is so versatile that it does not prescribe the look of the house at all. Perhaps paradoxically for such a lightweight form of construction, the architect also likes the way that services can easily be accommodated inside thick panel walls.

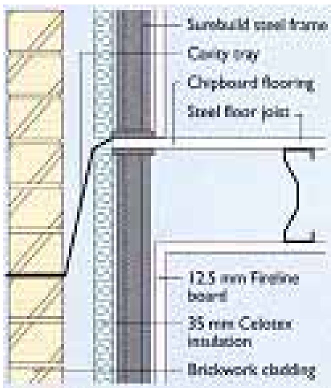
Photo 3.21 The steel parts have been pointed out by red paint

Photo 3.22 The panel structures of the house

Structural Features

The house uses steel framing wherever possible. The structural frame is generally in light steel panels with key members in hot rolled steel (see isometric structural system in Figure 3.3). Floor joists are all steel, while the roof deck is in profiled steel, curved longitudinally over shaped steel angles to form a barrel vault. All structural walls are prefabricated panels made from cold-formed steel sections with insulation and brick tie channels attached in the factory. The fact that the elements are bolted and screwed together is a huge advantage for easy construction and maintaining recyclable elements for the future. Despite light steel's clear advantages in terms of construction time and dimensional accuracy, the building cost of the house proved to be similar to that of conventional construction. (SCI, Case Studies, 2000)





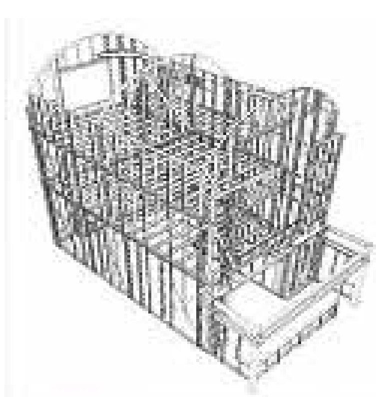


Photo 3.23 A view from the construction process

Figure 3.2 Brick wall cladding attached to the LGSF structure

Figure 3.3 The structural system of the house

<u>**3- Grahame White House on the NSW South Coast**</u>

Architect	Richard Barraclough
Contractor	Robert Gee, Cumnor, Oxon.
Structural engineer (foundation)	Ian Howdill & Associates
Steel frame suppliers	Steel House Frames Colorbond for roof frames
Location	Lake Conjola, New South Wales, Australia
Date	February-March 2002
Number of storey	1-2
Area	300 m^2
Structural system	LGSF with panel system construction method
Connection Elements	Bolts
Outdoor coating material	Zincalume Panels
Construction time	1 month

Photo 3.24 Grahame White House on the NSW South Coast

Design Features

The house was built on a sloppy site almost five meters above ground level on the lake side, supported by slender steel columns with substantial outdoor living areas towards the north east.

The use of steel contributes to the feeling of openness that owner builders Graham and Vicki White wanted to create. The house is built around an 'H' pattern and has three bedrooms and three bathrooms. It is a substantial 300 square meters, with a central core containing a kitchen, a lounge and a dining room. External wings on either side of the house have bedrooms, sitting rooms, garage and laundry inside. The roofs are designed to shade the decks in summer.

The approach was to be environmentally sensitive by keeping site disturbance to the minimum, hence the pole design and the commissioning of a thermally efficient design that would not rely on air conditioning in the hot summer months.

Structural Features

Photo 3.25 The structure of the house

The lightweight steel framing was another benefit, with the frames lifted into position on site by two people rather than the necessity of bringing in a crane with additional cost. The construction system was a panelized system that allowed light framing elements to be carried easily of the scattered house.

The structure was built by LGSF structural walls, which have been carried by column elements at the slope side. The load bearing wall elements have large windows at the bay looking façade. The covering panels are insulated. Automatic openers to high windows, which allow heat to be vented outside and operated by temperature-sensitive controllers, are a clever feature contributing to the home’s thermal efficiency. Graham White's company, Shoalhaven Gas Hot Water & Elements, has installed a wide range of energy-saving appliances to complement the thermally efficient design of the home, including automatic controls that turn lights off and on in the evening. (http://www.bluescopesteel.com.au/au/index.cfm/)

4- International Home Exports (IHE), San Diego

Architect	IHE architects
Contractor	Various
Steel frame suppliers	IHE
Location	Different places all over the world
Date	Since 1996
Number of storey	Up to 3 storey
Area	Various
Structural system	LGSF with panel system
Connection Elements	Self-tapping screws
Outdoor coating material	Chip cement board in most and Other coverings in case of order
Construction time	45 days after the house being ordered

Photo 3.26 LGSF House examples from International Home Exports (IHE), San Diego

Design Features

In 1996 the founders of IHE embarked on a new adventure by becoming the first production oriented, steel framing company in San Diego County. Through that process, it's been learned about steel framing, including simplicity in construction and the quality obtained in the finished product by building homes out of light-gauge steel. In addition, it's been discovered that the world's demand for affordable housing was not being met and the world was seeking an alternative to the archaic, slow and often-times structurally inferior method of building houses with concrete and concrete block.

Structural Features

The structure is the panelized LGSF system. No extra structural elements are needed rather than CFS profiles and exact number of bolts. The system is constructed by the help of panel elements, so there is no need for the extra wind bracing elements or strapping elements in between, but for the system to be held up easily extra elements are used as seen in the Photo 3.27. The adjustments are done at the building site. In this system after the framing is finished gypsum board is attached to the framing elements and color stucco covered, paper back metal lath elements are used for the exterior covering. The roof is designed with CFS elements as well, the roof frames are also prepared in the factory ready to be installed. The general structural details are standard details of the company.

All different types and sizes of the houses are built with the same methods, techniques and details. The standard profiles are produced according to the pre-designed construction systems in case of order and the transportation and construction are also done by the producer company. All the process is proposed to be finished in 45 days, whichever house is chosen from the catalogue.

Photo 3.27 Construction site of panelized houses (http://www.ihexports.com/)

3.2.1.3. Modular (Pre-engineered) LGSF Examples

1- Hall of Residence - University of Wales

Architect	Gale, Stephen, Steiner
Contractor	Director of Estates, University of Wales College Cardiff
Structural engineer (foundation)	Ove Arup & Partners
Steel frame suppliers	Durasteel
Location	Cardiff
Date	
Number of storey	4
Area	192 m²
Structural system	LGSF with modular system construction method with structural steel column elements
Connection Elements	
Outdoor coating material	Brick
Construction time	4 months in total

Photo 3.28 Hall of Residence, University of Wales

Design Features

The Birchwood Lane Project was the prototype for the TMT modular building system developed by Ove Arup & Partners in conjunction with TMT. This development comprised a four-storey, self-contained 64-bedroom hall of residence using a total of 80 modules.

The individual modular room units were 2.4m wide x 4m long x 2.6m high and were placed on either side of a separate corridor. The system comprised self-supporting steel modular boxes. These were supported at each corner and were capable of being stacked up to 12 storey without any independent structural frame.

The modular units were clad with a traditional brickwork outer leaf and a tiled roof. The fast-track construction (production) of the four-storey building took four months, which was important for the University client.

The interior, designed by Gale, Stephen, Steiner, was also modular in its concept. Fully fitted, prefabricated GRP modular units, incorporating toilet, shower, basin and accessories, were delivered to the factory ready for installation. The interior fittings were designed to be delivered to the factory 'flat packed' to minimize storage. They provided a combination of furniture, painted panels and pin boards, hung on a split batten system.

In the installation process, a close butt joint system is utilized that could move independently during transit. The completed room was locked in place by the doorframe, which was fixed to the module with screws and caps, allowing the removal of damaged panels or the refurbishment of the room at a later stage. This installation procedure took approximately 30 minutes. The fully fitted modules were delivered to site, tested and commissioned, requiring only the final connection of services.

The project was successful in proving the innovative construction system, high quality factory finishes, production tolerances and off-site commissioning.

Photo 3.29 Inside of a modular unit

Structural Features

The box modules were formed of Durasteel walls and profiled metal decking on a cold-formed steel framework. The load bearing rolled steel angle corner posts were attached to each module corner via acoustic pads. The modules were simply bolted together on site using splice plates at each level, taking advantage of the high geometric accuracy achievable under factory conditions. The stability of both the modules and the assembled building was provided by the diaphragm action of the module walls.

The unique connection detailing, together with the wall construction, produced acoustic insulation greater than 52 dB and excellent impact insulation. Fire testing of the wall construction proved a maximum fire resistance of 3 hours, justifying construction up to 12 storey.

The framework comprised cold-formed steel sections with hot rolled steel angles at the corners that provided the vertical support. The connection detail allowed for a neoprene joint that reduced acoustic and vibration transfer between the units. (see Figure 3.5)

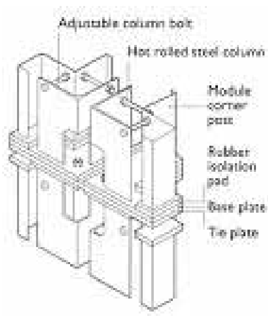


Photo 3.30 Ytong room modules

Figure 3.4 Connection detail of the modules

Additional stairs and communal areas were also provided. The brickwork was laterally supported by the system of units. A low roof pitch was constructed conventionally. (SCI, Case Studies, 2000)

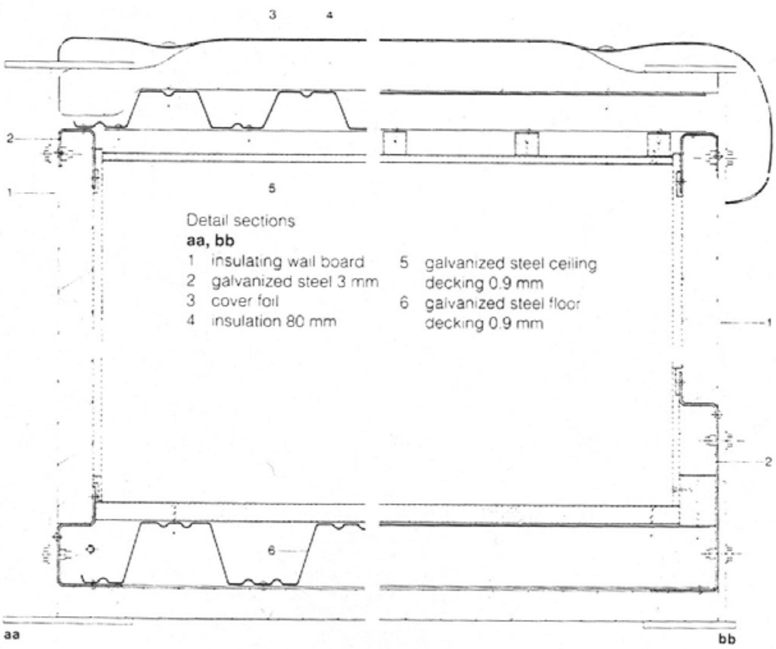


Figure 3.5 Plan section details of LGSF modules

2- Murray Grove, Hackney

Architect	Cartwright Pickard Architects
Contractor	The Peabody Trust (client) Kajima UK Engineering (main contractor)
Structural engineer (foundation)	Whitby, Bird and Partners
Modular manufacturer	Yorkon
Location	Hackney, London, UK
Date	1999
Number of storey	5
Area	
Structural system	LGSF with modular system construction method fastened by the help of steel cables
Connection Elements	The steel cables on the façades
Outdoor coating material	Brick & Glass
Construction time	Less than 2 weeks

Photo 3.31 Murray Grove, Hackney

Photo 3.32 A view from outside

Photo 3.33 The steel structural elements in the façade

Design Features

One of Britain's oldest Housing Associations decided to develop its latest venture with a pre-fabricated system. The Peabody Trust was becoming increasingly dissatisfied with the results they were getting in their current traditional projects. Construction time-scales were taking 50% longer than forecast and quality was suffering. Consequently, in an attempt to achieve a fixed-price contract, with faster delivery on site and at a good level of quality, the Trust decided to develop this scheme as a prototype in prefabricated housing using modular or volumetric construction. The accommodation is targeted at young single people, couples and flat sharers, who might prefer low-rental housing for a few years rather than the greater commitment of a mortgage. If this project would be successful, they will look at large-scale industrialized production.

The single-bedroom flats are made up of two 8 m x 3.2 m modules. The two bedroom flats comprise three modules. All bedrooms and living rooms have internal dimensions of 5.15 m x 3 m, enabling living rooms to be used as bedrooms. Internal corridors have been omitted to save space, with access to flats achieved by external balconies facing the street. Each flat also has a private balcony facing a communal garden.

The flats came to site in two modular units that are fully fitted-out, plumbed and decorated. Furthermore, the roof elements and the circular entrance hall, lift and stairwell were delivered as modular elements.

Electric storage heaters heat flats. Kitchens and bathrooms have mechanical extract ventilation.

The prefabricated construction is openly expressed in pre-cast concrete balconies, steel-rod cross bracing and clip-on terracotta tile cladding, all of which will be dry assembled on site.

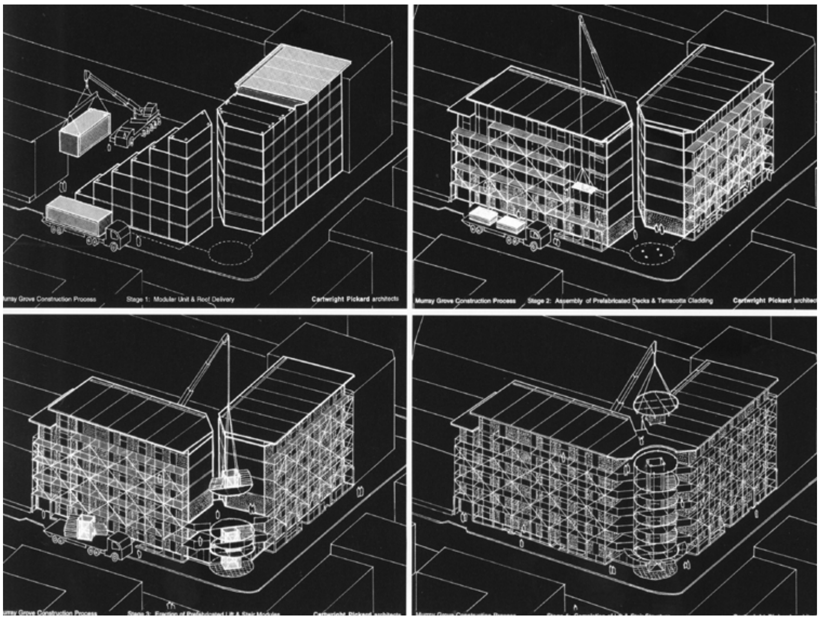


Photo 3.34 The construction process drawings

Structural Features

All light steel modules are manufactured in the factory, and will arrive on site fully equipped with bathroom and kitchen fittings, doors, windows, trim and internal decorations. The modules are 8 meters long x 3.2 meters wide and are 3 meters high. The light, steel framed boxes developed by Cartwright Pickard were designed with the same dimensions as Yorkon's standard hotel-room modules so they could be manufactured on the company's existing production lines. The money saved by building quickly allowed the remaining funds to be put toward good quality doors, windows and fixtures as well as fittings that were screwed in place at the factory. The roof is supplied as steel panels. The roof, distinctive circular entrance, and stairwell were delivered to the site as modular elements. Fine materials and careful detailing contribute to the high profile and quality architectural image. The building got the "(RIBA) Building of the Year Award" in 2000.

Photo 3.35 Construction process

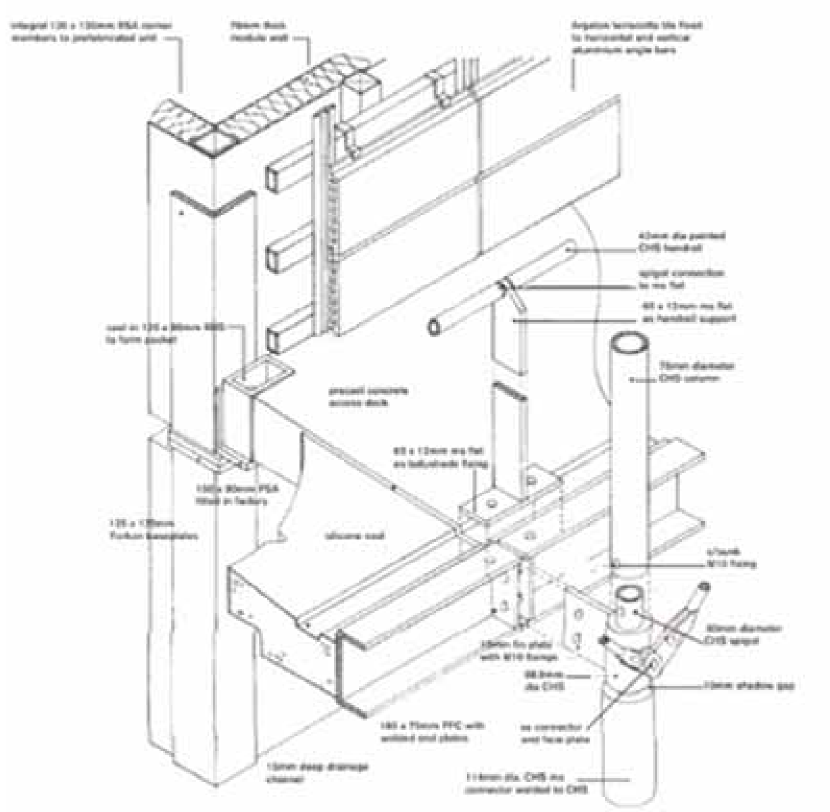


Figure 3.6 Main structural detail

The elevations are clad with a clip-on terracotta rain screen cladding system chosen for both its architectural qualities and its ability to be integrated into a dry construction system. Perforated aluminum screens form a translucent veil in front of the balconies and stair tower.

The cylindrical stair tower, enclosing a glazed lift, is located at the junction between the two wings at the highly visible pivotal corner of the site.

Photo 3.36 Exterior view from the backyard

Photo 3.37 Exterior view from the backyard

Photo 3.38 Interior view

Photo 3.39 Details of the exterior structural system

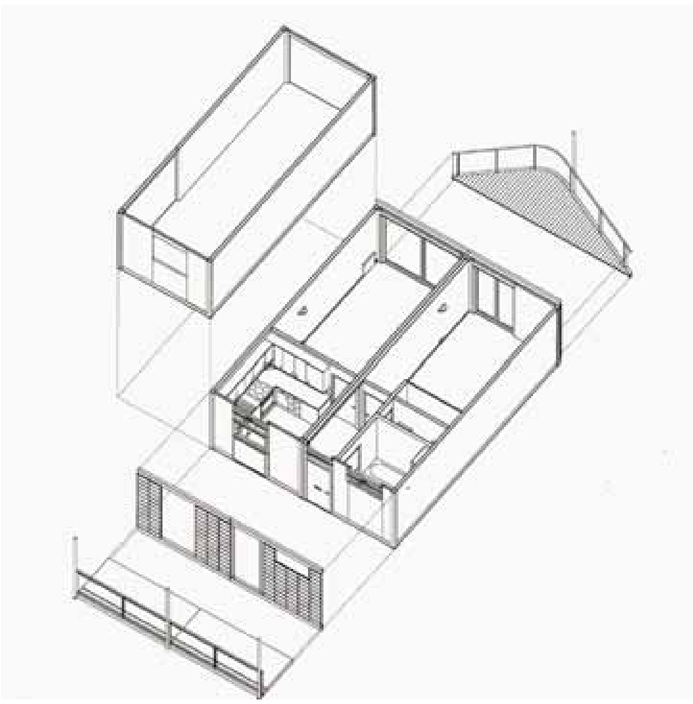


Figure 3.7 Detailed module structures

(SCI, Case Studies, 2000; Arieff A. & Burkhart B., 2002; Photos from personal archive)

3- Raines Court in London

Architect	Allford, Hall, Moneghan, Morris (AHMM)
Contractor	Peabody Trust
Structural engineer (foundation)	
Steel frame suppliers	Corus
Location	Stoke Newington, London, UK
Date	Spring, 2003
Number of storey	6
Area	
Structural system	LGSF with modular system construction method
Connection Elements	Steel connectors
Outdoor coating material	Metal Cladding
Construction time	9 months (Production process included)


Photo 3.40 Views from Raines Court in London

Photo 3.41 Raines Court, London

Design Features

The site of Raines Court is on the corner of Northwold Road in North East London, bounded on one side by the traffic spilling from Stoke Newington into Hackney and on the other by the local railway line from Liverpool Street station and the site doesn't allow any building interruption. So, modular system of LGSF is suitable for the area.

Raines Court comprises 61 units divided into 41 two-bed apartments, 11 three-bed units, 8 one-bed live/work units and a single one-bed apartment. This mix of sizes is one of the examples of an increasing maturity in modular thinking, logic would suggest that a single size of apartment would be the simplest to manufacture but planning constraints required a mix of accommodation. The trick is allowing sufficient flexibility within the factory processes to make as much as possible in the same way, and trying to incorporate changes in plan form - allowing different layouts and occupancies - to simple and standard types and locations. The architects, Allford, Hall, Moneghan, Morris (AHMM) adopted a T-shaped building that ranges in height up to six storeys.

AHMM wanted to give each resident a private entrance to his or her apartment. In order to do this, part of the bedroom module is produced as an 'outside court' which takes the resident off the (fairly standard) deck access walk way, and into their own space before arriving at the front door.

On the other side of the units another balcony, again part of the module, is accessed from the living room. It is these balconies, which can be seen from Northwold Road and have metal-clad colored walls. The palette of greens, blues and the occasional yellow produced in collaboration with the colorist Charlotte Ingle breaks up the flat frontage facing Northwold Road.

Elsewhere the emphasis is on self finished materials, tongue and groove larch timber, zinc cladding and galvanized steel structural sections make up the exterior façade, the internal courtyard favors more painted surfaces and uses suspended etched glass panes which spell out the word 'Raines'. The building won the RIBA Award 2004.

Photo 3.42 A view from Raines Court

Structural Features

Photo 3.43 Construction process of the Raines Court

In all project 127 modules have been used at Raines Court, these were fabricated by Yorkon in York who also produced the modules for Murray Grove. In order to maximize the benefit from modular construction techniques the size of the module used was pushed to the upper limits of the technology. Each module measures 11.6m x 3.8m – still road transportable but allowing a two-bedroom apartment to be made from just two joined along the long sides. The design is optimized for acoustic performance and the modular format has been proven to work well in this context. Thermal performance is achieved by two layers of insulation – one in between the studs of each individual module, the second forming part of the external cladding. The cladding materials were applied in the factory, as the proximity to the railway line made craning anything but the modules time – consuming and costly. As a result the joints between modules are expressed, covered with zinc 'spandrel panel'. While some may argue that this accentuates the boxes it is hard to deny the logic, which dictates that the maximum amount of work must be undertaken off-site to reap the potential of modular construction.

Photo 3.44 Exterior façade view of the Raines Court

Photo 3.45 Elevations from back façade

Photo 3.46 Main structural element-base connection detail

Photo 3.47 Roof structure detail

Photo 3.48 Exterior covering material

(Photos from the personal archive; http://www.corusconstruction.com/page_9017.htm)

3.3. House Examples from Turkey (with LGSF system)

1- Standard LGSF House Models of Akşan

Figure 3.8 Elevation examples of the standard house models

Figure 3.9 Plan examples of the standard house models

Design Features

Akşan Building Company is one of the biggest companies in Turkey that produces and applies the LGSF construction system. The designs that they suggest for the direct customers are the American style houses. They have around 30 house models (1-2 storey) that can be detected from their web site. When the designs are examined, it can easily be seen that the designs of the houses they offer are the typical American style single-family houses.

<u>The Structure</u>

Akşan Building Company works mainly as a producer and consultancy company. They often sell the LGSF system panels that they produce in their factory in ordered sizes, but they also sell the profiles without joining them together. They suggest panel systems which are joined together with self-tapping screws and steel joint elements on corner and junction points, with OSB panels attached on the system, on the walls, floors and roofs. The LGSF construction techniques and structural details of the company are briefly shown in their website with all the detailed profile data. (www.aksanworks.com)

<u>Various different mass-produced housing projects done with the constructional LGSF system and consultancy of Akşan Building Company in Turkey</u>

Photo 3.49 Oyak Çankaya Houses, Zirvekent Ankara, 120 & 216 m² villas

Photo 3.50 Sima Derbent Houses, İzmit, 200m² 40 villas

Photo 3.51 Serdivan Houses, Sapanca İstanbul, 183m² 22 villas

"The structural members are hot dipped galvanized steel cold-formed into U, C, Z and sections at the AKŞAN FACTORY on roll form machines. The thicknesses of the sections are 0,5-2,5 mm. The members are then fastened to each other using self-drilling co-polymer or galvanized screws into panels or trusses. These panels are then fastened to each other on site to form the frame of the structure. Sheathing is applied on the panels using OSB 3, which also contributes to the structure, converting the panels into shear walls capable of bearing vertical and horizontal loads that may be the results of earthquakes and strong wind." (www.aksanworks.com)

2- Ümitkent Steel Houses

Architect	The architects of the Köşk Building Company
Contractor	Public work
Structural engineer (foundation)	Köşk Building Company staff
Steel frame suppliers	Köşk Building Company
Place	Nilüfer County, Bursa
Date	2002
Number of storey	1 or 2
Location	Koyapa mass produced housing site
Structural system	LGSF with panel system construction method and hot rolled steel elements
Connection Elements	Self tapping screws
Outdoor coating material	Chip cement board in most and Other coverings in case of order
Construction time	90 days

Figure 3.10 Site plans and plan

Photo 3.52 Construction process from the Ümitkent Houses

House Types which are also the standard house models of Köşk Construction Company

Photo 3.53 Safranbolu Kiosk

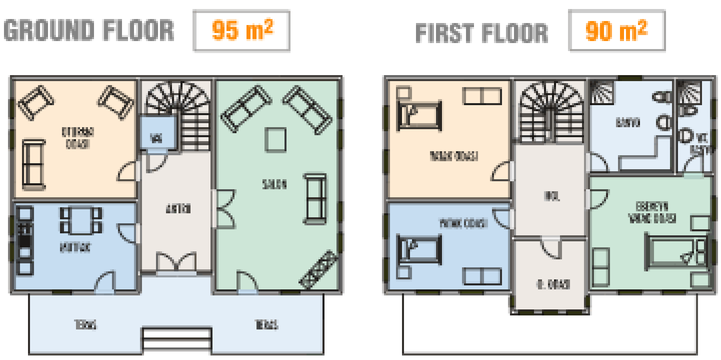


Figure 3.11 Safranbolu Kiosk – Floor plans

Photo 3.54 American Kiosk

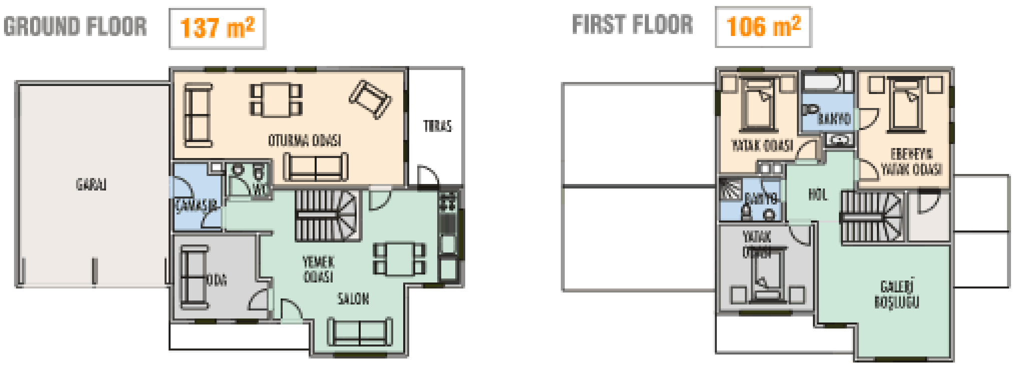


Figure 3.12 American Kiosk – Floor plans

Photo 3.55 Bolu Kiosk

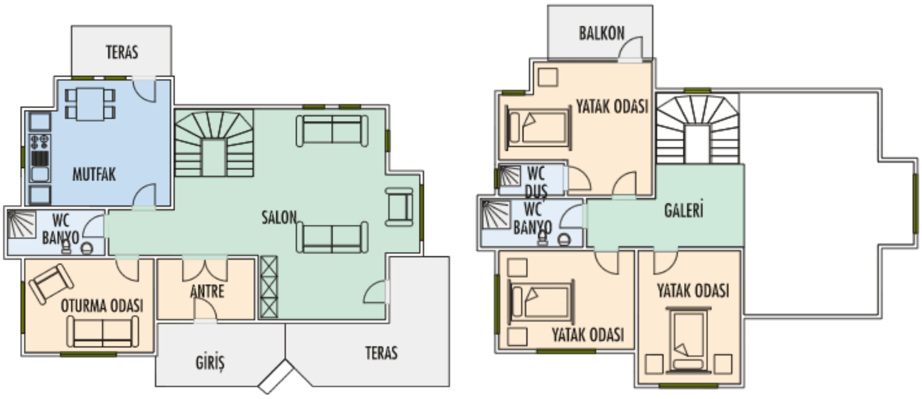


Figure 3.13 Bolu Kiosk - Ground floor plan 116m², First floor plan 90m²

Design Features

The designs of these houses were prepared according to standard plan types and the CFS profile cost analysis. The Köşk Building Company, which is another important producer company of Turkey, designed these houses as their proposed designs for the customers and this Ümitkent project is the one that they can offer all the prototype projects to the people on the same site. The residential "site" offers facilities like security control, private gardens in 384m² owned space for each client, swimming pool, 2 personal parking places, site organization and sports facilities.

In this housing project, the company offers 1-2 storey house models, which range between 140 and 500 m² in area. The houses are defined to be modern, practical, fast built, aesthetic in look, ready to oppose the standard comfort conditions, sustainable, suitable for living every season in and earthquake-resistant. As seen in Safranbolu House model, the Turkish traditional house features have bee used. The façade look of the house and the plan has been taken from the wooden frame traditional house of the Safranbolu area in Turkey. The chosen house model at the following site in any size is prepared and constructed in 90 days according to company's word.

Structural Features

The structural system is LGSF built with panels in Köşk Company, too. The LGSF panels are joined together with bolted-joint elements and self-tapping screws. Then the frame is covered by OSB outside the whole web system and covered with various covering elements as plasterboard or plastic siding boards. The panelized method structural system is typical in all the Turkish companies.

Photo 3.56 Structure of the Abant Kiosk

"In Köşk Steel Construction System, everything starts with design drawings. During a design phase, design drawings are produced as per the National Earthquake Codes based on ASTM, DIN and Turkish standards. In addition to ready-made projects, custom-made projects suitable for your specific needs or your existing projects may be implemented. Your ideas and demands turn to reality with Köşk Steel Construction System. Just ask for it.

Here at Köşk Steel Construction, static engineers figure out by means of special software load-carrying carcass to be used in a structure along with all other details and manufactured at the factory under strict quality control observations.

In Köşk Steel Construction System, structures are designed based on the dimensions of inner and outer coating and insulating materials. All walls serve both as load-carrier and partitioning elements. When a construction has been finished, no additional structures are used for coating processes." (Köşk website, www.kosk.com.tr)

3- Yamaçevler of EN, İzmir

Architect	EN Architects
Contractor	EN Building Enterprise
Structural engineer (foundation)	Akşan
Steel frame suppliers	Akşan
Location	Ulukent, İzmir
Date	2004
Number of storey	2
Area	220 m²
Structural system	LGSF with panel system construction method
Connection Elements	Self-tapping screws
Outdoor coating material	Chip cement board in most and Other coverings in case of order
Construction time	2 weeks

Photo 3.57 Cordelia House, İzmir, TURKEY

Photo 3.58 A view from Cordelia House

Photo 3.59 Structural system of Cordelia house

Photo 3.60 Structural steel joint elements

Design Features

This house is designed to be one of the 4 different designs of the first step of the Ulukent Houses. It's a 3-bedroom 220 m² standard house. The housing site will have social facilities and landscape design as in the many of the new building sites in Turkey.

Structural Features

The Akşan engineers in accordance with the designed house model of their company made the structural system design. The wall panels of the Company are brought to the site ready to be adapted, while the roof and floor structures are made at the site from the standard accurate Akşan profiles. Extra structural steel elements are used in the system, as well. (Photos from the personal archive)

3.4. A General Comparison of the LGSF House Examples in and out of Turkey

It’s hard to compare the Turkish building market with every other different country one by one, but it’s possible to tell about the similarities of the Turkish LGSF housing production and marketing systems with some countries.

The two main companies that produce CFS profiles for LGSF systems of Turkey are also offering some model houses ready to be constructed with their own made profiles as seen in the examples. For the codes of the profiles and the general design principles, these companies had used the LGSF Standards of the Eurocode and AISI (American Iron and Steel Institute). There are no standards prepared for the LGSF houses in Turkey yet, so the one or two storey LGSF houses are made in the light of the stated standards. Only the foundation system is done according to the TSE (Turkish Standards Institute) standards which are made for1-2 storey concrete houses, and this causes the LGSF system to have base elements stronger than needed.

The company profile of Turkey is similar to American, Canadian and Australian companies at the moment, which offer standard model houses that are ready to be produced and built, which can also be followed in the previous examples. The Turkish LGSF housing market isn’t developed as much as these countries, so the houses aren’t made ready and packaged to be transported. Also “make your own house” projects aren’t preferred in Turkey. The main reason of this is the financial status of the client in Turkey. Still, to build a 1-2 storey legal house is not affordable for public and light gauge steel houses are designed mostly for upper class clients. The building stocks of LGSF houses in Turkey are mass produced examples commonly made up according to the decided plan of the client with the company’s architectural consultancy. The “site” tradition of Turkey’s upper class housing is combined with American “choose your own house model system” as seen in the projects above. The house plans are made according to standard typical house types of the world. There are only a few unique house designs and different application examples.

Turkey can be criticized for its imitating approach. The imported houses and also the ones, which are produced in the country, do not really oppose the residential market needs and variety. The house plan types, the spatial qualities or the land uses are the facts to be argued on in the near future of the LGSF housing in Turkey.

As other construction systems, LGSF has been imported to Turkey by the building companies without interrogating the general features of the system. In the examples part, it had been said that the dimensioning of the LGSF system has been taken from the traditional wooden house. Thereby, the standard typical products in the market can be used in the world, but in Turkey the wooden house tradition had been left in the last century and the market products are not sized according to wooden house dimension data. Also the new planned LGSF houses in Turkey do not have a relation with the traditional Turkish house.

The fast venture of Turkey in LGSF systems again left no time for the authorities to criticize. The lack of standards prepared for Turkey conditions cause the experimental dimensioning techniques with the help of the foreign pioneer companies. Also because of the lack of architectural knowledge about the system, the designer architects can't really participate enough in the LGSF house designs for the moment.

This kind of marketing policy always excludes architectural look from the design in the world, too. When we have a look at the examples it can easily be followed that most of the LGSF company houses in the world are not designed by a specified architect. And the design quality difference of the houses designed by individual architects and company typical house designs can be easily recognized. The architects should first examine a new construction system in order to design good and different buildings of the future.

Although the production and marketing model of America has been followed by the Turkish LGSF companies and the design problems had been consulted by AISI, the stick-built construction method which is preferred in some American companies haven't been accepted by the Turkish companies. The site-built construction in Turkey doesn't still give accurate system elements and the LGSF system doesn't tolerate any dimensional defects. Also the hardness of transportation of the stick elements; especially the full- length two storey studs on the Turkish transportation network causes not to use the stick-built method. Need for cranes and more equipment at building site are other disadvantages of this method in Turkish building market conditions.

The Turkish housing tradition turned into 4-5 storey apartment blocks even in the counties, so the British modular systems which can be reproduced up to twelve storey looks as it can be an alternative for the Turkish mass-produced building blocks at first look. Yet, to place the big and heavy modules cranes are necessary and the transportation becomes a big problem.

In Turkey panelized method is preferred. The panels were produced in the factory and transported to the building site as frames of CFS profiles and then fixed together to build the frame web system, the installation elements are placed after the web frame is done. Self-drilling and self-tapping screws are commonly used in joining the system elements. It's easier to fix the system by this way, yet the bolt connections permit the system to be unfixed to its component panels and been removed easily. The bolt connections also give chance for the future recyclability of the CFS profiles. Also all Turkish companies import OSB as the main structural coating element while plywood and gypsum boards are other alternatives in the world.

The most important advantage of the LGSF system in Turkey can be summarized as it's accuracy in construction and earthquake resistant light weight structure.

There may be other alternative uses of the LGSF system for Turkish residential building market. The alternative uses of the LGSF system will be examined by some examples in the following section in order to understand some of the alternative LGSF system uses in the world. The alternative examples are taken from; (SCI, Case Studies, 2000; www.kosk.com.tr; personal archive).

3.5. Alternative Uses of LGSF System with Various Examples from the World

1- House at Milldale, Aberdeenshire

Architect	Richard Murphy Architects
Contractor	A couple in 30s.
Steel frame suppliers	
Location	Milldale, Aberdeenshire, Northern Scotland
Date	
Number of storey	1
Area	
Structural system	Combination of lightweight steel and solid masonry construction, designed to respond to northern climes
Connection Elements	Bolts
Outdoor coating material	Stone and glass
Construction time	

Photo 3.61 House at Milldale, Aberdeenshire

Photo 3.62 Solar glazing systems in the house

In this house only in the solar glazing roof element and in partition elements, the LGSF system had been used.

2- Fareham College, Art Block Roof

Architect	Trowbridge Steel and Partners
Client	Fareham College
Steel frame suppliers (Capella over-roofing system)	Ward Building Components Ltd.
Location	Hampshire, UK
Date	1996
Number of storey	1 (new roof system)
Area	
Structural system	Lightweight steel construction built at site by stick-built method
Connection Elements	Bolts
Outdoor coating material	Trapezoid board &glass


Photo 3.63 Fareham College, Art Block Roof
Photo 3.64 Main structure

In the Fareham College, the new roof system provides structural support in light steel for a new-pitched roof surface. Its key characteristics are its lightweight and its large spanning capability (up to 30 m in certain circumstances), which allows it to span from one side of a building to the other without placing any load on the intervening structure. The result is satisfying for both architect and client that encouraged the use of the system as a roofing element.

3- Attic Addition, Ankara

Architect	
Client	
Steel frame suppliers	Köşk steel framing Company
Location	Ankara, Turkey
Date	
Number of storey	1 (penthouse addition) over 3-storey concrete structure
Area	
Structural system	Lightweight steel construction built by panelized construction method
Connection Elements	Self-tapping screws
Outdoor coating material	
Construction Time	

Photo 3.65 Attic Addition, Ankara

The Penthouse was designed to add an extra floor. By using LGSF structure, the extra loading on the existing structure could be minimized.

4- Extension to Management College

Architect	Terrapin Matrex
Client	Ashorne Hill Management College, Leamington Spa
Steel frame suppliers	Precision Metal Forming (cassette panels)
Location	Ashorne Hill Management College, UK
Date	
Number of storey	2
Area	500 m²
Structural system	Lightweight steel construction built by panelized construction method
Connection Elements	Shot-fired pins (screws)
Outdoor coating material	The storey-high cassette panel
Construction Time	

Photo 3.66 Extension to Management College

Photo 3.67 The structure of the extension

The design had to be sympathetic to the existing yellow Oxford shire stone building from the 1890s. The local planners approved the mixed use of stone and large steel cassette panels in Prussian grey from British Steel's new Celestia range. This gave the new facility to a modern appearance, but was complimentary to the side extension to the College building.

5- The Canopy of Hackney Empire Theater Extension

Architect	Tim Ronalds Architects
Client	
Steel frame suppliers	
Location	Hackney, London, UK
Date	Original theater: 1901, Extension: 1999-2004 (under construction)
Number of storey	5
Area	700 m²
Structural system	Lightweight steel construction
Connection Elements	Bolts
Outdoor coating material	Stone covering
Construction Time	Varies

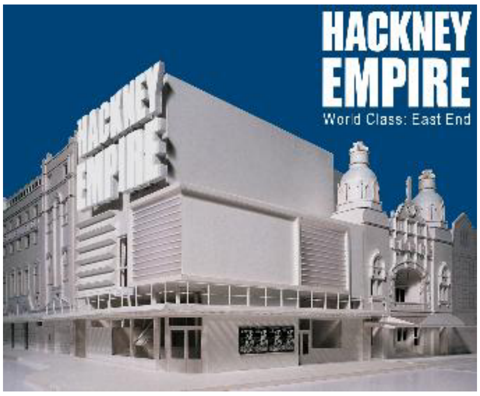


Photo 3.68 Hackney Empire Extension Model

Photo 3.69 The Entrance Canopy

The Hackney Empire Theater is decided to be renovated in 1998 and in the renovation project the new extensions are made with LGSF (acoustically insulated) wall systems. The canopy of the new entrance is also made of cold formed steel sections and it's been carried by the old wall system. The canopy is designed as an element that will be walked on as a terrace after the project is completed, so the sections are fairly thick.

3.6. Advantages & Disadvantages of LGSF System

The LGSF system provides the following advantages:

- Lightness in weight: LGSF is a lightweight construction system.

- *earthquake resistant*: The more a building system is light in weight, the less it takes the earthquake impacts. The continuous load distribution on system also helps the system elements to react together like in masonry constructions.
- *easy & fast montage*: The system is quick to erect, allowing site assembly without any crane work.
- *suitable for poor ground conditions*: A steel stud wall weighs typically only 20% of an equivalent block work wall. This reduces foundation loads and foundation settlement, which also makes the system suitable for any poor ground conditions and earthquake occasions.
- *easy portability & storage*: As the system is light, the elements can easily be lifted, so the system is portable. It can easily be carried and stored.
- *fast production & construction*: For faster production processes, the use of light gauge steel is recommended because of the shorter periods needed for production, transportation and installation compared to other systems.
- *suitable for additions & extensions*: The adaptation of the system to other construction systems is possible and the integration of LGSF system is easier compared to the integration of many other construction systems, because of its lightness in weight. The system is suitable for building additions like roofs, penthouses of the multi-storey buildings or any other additions that would cause extra load impacts on the existing structure.
- *ease of prefabrication & mass production*: is a major advantage of the system. Sections which are light in wight, can be prefabricated into larger units by either welding or fixing by bolts or self-tapping screws. Mass production techniques of light sections lead to considerable economies for the runs of large production and they also give dimensional accuracy to facilitate repetitive production. Easy

and fast construction of the accurate CFS profiles encourages the use of the LGSF system construction system.

- Cold formed steel section properties: The light weight CFS sections are the main structural elements of the Light Gauge Steel Framing System.

- *smaller section area need*: For CFS profiles, high strength to weight ratio and stiffness are major advantages to achieve longer floor or truss spans with smaller section areas compared to other constructions' system elements. This causes minimum structural element usage, hence easy and economic (material economy) construction.
- *variety of cross-sections*: A great variety of cross-sectional shapes can be produced with CFS material for different LGSF system projects.
- *dimensionally accurate cross-sections*: The CFS profiles produced for LGSF system is manufactured in factories by CAD/CAM methods by computers, which make them dimensionally accurate, and standard in all mass-produced amounts.
- *homogeneous material character*: Steel is fairly homogeneous & isotropic compared to other structural elements like wood or concrete which is an advantage for keeping the same properties through out the whole horizontal stud section.
- *section properties*: CFS elements do not show any cracking, torsion deflection, breakage or decay. Light gauge steel doesn't change in characteristics through out the cross-sections except the folding points of the profiles where not much difference in property can be observed.
- *load-bearing material*: Steel admits deformation under load and when load is freed, regains its original strength. This elasticity makes steel the most favorable material under loading (like earthquake, wind and other loads).
- *earthquake resistant material*: Steel is an earthquake resistant building material with its elastic material characteristics that easily takes earthquake impacts. Strength of steel is rather high. Its maximum allowed tensile strength is 1440 kgf/cm2.

- Advantages in the production & construction process of LGSF system:

- *dimensionally precise construction*: Cross sectional shapes and lengths can be formed to very close, consistent tolerances, which leads the elements to dimensionally precise construction that is important in the fitting of the building components together.
- *clean construction site*: Lightweight steel construction provides a clean building site, building waste and pilferage is greatly reduced with prefabricated and pre-manufactured building components in this system.
- *pre-designed system*: The system should be pre-designed from head to toe before construction. Even the integrity of the service parts in the system has been solved in the beginning of the production process by the pre-punch of the openings for the services (before or after forming the steel sheet elements into profiles). This provides the system, the advantage of being well-shaped and accurate.
- *dry construction system*: Construction using CFS profiles does not rely on wet trades. This fact also helps the clean usage of the building site and decreases the construction time of the system. In this system, there's no need for the organization of the drying-time period.
- *predictable timing*: Weather conditions do not really affect the construction process of the LGSF system because of its dry production. Also the construction steps are pre-defined and the timing of construction is definite in especially the modular and panelized construction methods.
- *modern & flexible structural system*: In steel constructions, lightweight, flexible and modern materials can be applied easily. Steel framing accommodates all types of finishing elements.
- *flexible & adaptable system*: Steel is an adaptable material, so attachments to the system which give chance for the future extensions can easily be done. Moveable LGSF internal partitions are also maintain adaptable planning.

- Maintenance advantages of the LGSF system:

- *durable in all weather conditions*: As well as other loadings on system, lightweight steel construction can resist to all weather conditions, with the right covering components.
- *termite proof system*: LGSF structure has no termite problems like wooden structures, but the usual standard covering & insulation elements of the system are not termite-proof like the CFS profiles themselves.
- *not affected from humidity*: Unlike timber and masonry, there is no tendency for longer-term movement. Steel is not affected by changes in humidity. Typical shrinkage and other strains in timber and block work can be up to 3mm over a storey height. Thermal movements of steel (yield point) are less than aluminum and compatible with concrete and masonry.
- *resistant to corrosion*: Galvanized light gauge steel is a stable material, with predictable performance. Galvanized material is resistant to corrosion and the standard system has a long service life as the British Steel Institute declares between 60-100 years. Cold formed steel sections used on the warm side of insulation in external walls have proven to be extremely durable. For increasing the durability of the outside materials and heat comfort conditions, over coating of the system from outside needs extra care.
- *steel elements are non-combustible*: Unlike plastic and timber, steel is non-combustible. Yet fire protection is required to enable or slow down the reach of direct flames to the material.
- *made of reusable & recyclable material*: Steel (also cold formed steel) is adaptable and can easily be re-located, re-used and recycled. CFS elements are recyclable repeatedly without degradation or loss of property (the material can be defined as sustainable & ecological).

- *Competitive Cost*:

LGSF system is an affordable system. It can compete in prize with wooden construction and with conventional concrete system which is the main construction system in the building market of Turkey at the moment.

The LGSF system provides the following disadvantages:

- *Only suitable for 2-3 storey constructions without extra structural elements:* The LGSF system is feasible up to 3-4 storey buildings; there are still no applications of this system in multi storey buildings without the support of different elements.
- *Architectural design handicaps:* The design of the building is limited with the modular system defined by the cold-formed steel profile manufacturers. According to economies in profile production, it's more feasible to produce the same CFS profiles in large amounts for the manufacturers. Mostly the designs to be constructed depend on the loading capacities of the already manufactured profiles, so architectural design handicaps exist in such occasions.
- *No tolerance for any mistake in the production & construction of the system:* The system should be set professionally otherwise it is hard to keep the system safe in any uneasy condition. Everything should be organized in detail from beginning to end in order to maintain the long-living, safe and healthy residential units.
- *Need for Industry:* For obtaining accurate CFS profiles and a precise, healthy structural LGSF system. Computerized techniques must be used.
- *The heat constant of CFS profiles is high:* The λ (48) of cold-formed steel is considerably higher than the λ of wood and many other constructional materials that affects the circulation of air. The heat transfer so the heat loss in the CFS profiles is extremely high that the system should be over coated with highly insulated outdoor layers in order to keep the standard heating conditions.

- *Dangerous in fire:* CFS profiles may leak at 180 °C which makes the LGSF system dangerous in fire occasions. The main reason of using the system mainly in 1-2 storey buildings is basically the unhealthy behavior of profiles under fire.
- *Usage of some plastic based elements in LGSF systems:* The system materials (the covering and insulation elements) are mostly plastic based materials, which may cause some biological livings to settle on and can threaten the human (or plant and animal) life. Termites or bugs may affect gypsum board or some insulation elements.
- *Air circulation:* The system details usually cause the system to act as a non-breathing cell. Air circulation problems may cause harm in the health of the living creatures in the house. The main structural elements (CFS profiles) should be protected from the outdoor effects, so they should better be taken inside the outdoor covering elements even if they had been perfectly galvanized, this is the main point where air circulation problems occur and ventilation systems may be needed for some projects in order to maintain the perfect comfort conditions.
- *The indoor covering elements are fragile:* The standard indoor covering elements of the system are usually chosen from light materials such as plaster board which help the structure to weigh less than the others, but these covering elements can easily break or crack, so the LGSF system installed with these covering elements can be questioned for life living houses.
- *Impossibility of changing the place of the main service elements:* Although the system is available for future adaptability and enlargements, the integrity of the services for an existing panel or wall cannot be easily changed. The pre-punched holes can only be opened while forming, so mostly there’s no chance for later operations in the service facilities of an existing part.

CHAPTER 4

CASE STUDY: "POST-DISASTER" HOUSING UNIT PROJECT PROPOSAL, CONSTRUCTED WITH LGSF SYSTEM

4.1. Definition of "temporary & permanent post-disaster housing"

4.1.1. The Definition of Post-Disaster Housing

Briefly, a post-disaster housing unit is a house, which is built to solve the shelter problem of the people during or after the disaster occasions temporarily and/or permanently.

4.1.2. Post-Disaster Housing Types (According to Usage Period)

Right after the natural disaster, the houses built for emergency and rehabilitation periods which can be fixed or built in a short period and can be demountable for reuse, which maintains the optimum comfort conditions for living are the "temporary post-disaster housing units".

In the disaster area, during the re-building process when people are starting to live the routine daily life, the houses that are built in order to maintain the Standard daily living conditions are called to be the "permanent post-disaster housing unit". These houses are preferred to be built with materials that save from building time.

According to the thesis of Berna Baradan, the most suitable and healthy way of solving sheltering problems after the disaster occasions is to solve it by the "temporary post-disaster housing units" in the rehabilitation period. The rehabilitation period can be defined as, the period after the emergency period (period starting with the disaster). The tents, pneumatic structures or foldable structures are usually used in the first days after the disaster occasions (while the emergency period) or the people are transferred to the hosting areas of the governments if possible. In the first week, the temporary houses should be completed in order to transfer the disaster people before the permanent houses are built. The emergency period shelter usage time should be limited at most by two weeks, but it didn't last so in any application (Ervan, 1995). The maximum living time in the temporary housing units should be in between 1-3 months at maximum 6 months. In America the people that lost their houses are removed from the "temporary post-disaster housing units" in the 366th day (1 year) by force if they do not leave it, the unit has been pulled down. (Emery, 1981)

In the Ph.D. study of M.K. Ervan the "temporary post disaster housing" is defined as; *"... Are the houses that can be pulled down to its components in order to reaffix; that can be packaged, easily carried and stored; the worn out capacity and fixing costs are low, while they can easily be fixed; that has been prepared as units in the factory ready to be fixed at the building-site; the montage process should not require any special knowledge or equipment; the montage process could be done by the disaster people by the leadership of some directors without extra education, if needed also military force and extra workmanship can be use in montage; because of all those reasons the components of the building should be designed as giving chance to easy montage and demountage and while those processes the building element characteristics should not change and no extra materials should be left after the built up."* (Ervan, 1995, p. 46)

S. Acerer defines the "temporary post-disaster housing unit" as: *"A temporary shelter, is the space where disaster people can use by paying a little rent or for free until they can earn the money to build a permanent house." in his master thesis.* (Acerer, 1999, p. 127)

I propose to eliminate the post-disaster shelters as only two different shelter units rather than three (tent, temporary shelter, permanent shelter). Like Ervan and Baradan, I believe to keep the people in temporary post disaster-housing units until the permanent ones are built for at most 6 months with optimum living condition standards. I also think that these units can be designed as units to be fixed in a day or two, so the unnecessary tent or likely living units can be skipped in the period of adaptation after the disasters.

For my proposal, the "temporary post-disaster hosing units"; can easily be monted at site in a few days after the fast transportation period where the stocked premade packages are kept in the defined points on the map, so they should be mass produced units; placed at sites where nutrition, water supply and health services can easily be transferred, if possible nearby the demolished areas separately or collectively. They should be; houses which obtain the minimum living conditions structurally, physically and socially, but should not obtain the optimum living conditions of a standard house which would cost much more than it should and in this case people would be encouraged to live in them forever. Then the temporary-building site cannot be removed.

The standard optimum living conditions will be stated in the following section and the “temporary post-disaster housing unit” will be defined with its all features.

4.2. The Standard Optimum Requirements for “A Temporary Post-Disaster Housing Unit”

For the temporary post-disaster housing units, the most important fact that defines their qualifications is the usage period. The major problems for these short-term shelters are; protection from the outdoor conditions and to obtain the secrecy and for long-term uses (like 6 months), also various functions should be concerned in the design of the house. Pneumatic systems, steel, concrete or wooden-frame prefabricated residential units and mobile type (caravan) units where spatial quality and insulation needs are concerned are the examples that spatial quality is high. These systems which are preferred to be demountable; the total period of production, transportation and montage should be the two weeks after the occasion by the end of the period called to be the emergency period (Sey, 1999b). The ideal status is to keep the houses in the stocks of the government, ready to be transported and fixed-up after the disasters.

The temporary post-disaster housing units can be classified according to; plan types, structural system type, the geometrical shapes of the structural systems, material of the structural system and the industrialization status in the production. These classifications are taken and they’ve been summarized from the thesis of Berna Baradan and they all are explained in detail in the thesis named as *“GEÇİCİ AFET KONUTLARININ YAPIM SİSTEMLERİNE GÖRE İNCELENMESİ”*, which was written in 2002. The various examples are also classified in this study. The following requirements are gathered from the same study as well.

4.2.1. The Building-Site Requirements for "Temporary Post-Disaster Housing"

The Building-Sites for "Temporary Post-Disaster Housing" should obtain the social, physical and structural requirements of the homeless people although they're temporary.

a) The specific things that should be concerned in the election of the site of temporary housing:

The site should be nearby the previous living-site; because the disaster people don't want to go far from their places and their efforts for saving the rest of their belongings is a fact that helps them to survive psychologically. After the Gujarat Earthquake in January 2001, %90 of the disaster people resisted to live at the defined site because of the distance in between the temporary site and the place they'd previously lived. (Jigyasu, 2001)

If the service facilities of the site cannot be located in the site; the temporary communication, daily services, health, shopping and social activity centers should be reached easily from the site. De Chiara, 1984, gives the minimum and maximum distance standards. Also the transportation roads of the site should be big enough to maintain the various equipments to the site.

The temporary-site should not affect the reuse of the agricultural or forest areas, it better should be chosen from planted areas to avoid erosion. Also the site should be located far from the industrial areas so pollution at site can be controlled. In the choose of the site, the sandy soiled lands are preferred rather than clayed ones or swamps to keep the drainage of water which can be done in ideal %2-8 slope (The Sphere Project; De Chiara, 1984). The infrastructural conditions; canalization, electricity and water tanks must be supplied.

b) The Characteristics that should be concerned while planning in the temporary site:

The general site area should not be chosen as a very big area, which may cause security problems. However, keeping in mind that the population at site may increase in the near future, extra empty space for the new temporary units should be left at the site.

In the building-site, the space for each person with all living, service and transportation areas should better be calculated as 45 m^2. For the design of the site, to break the ordinary replacement and to obtain more secure units will be the main goal. The total units are divided to sub-groups of 10-15, in square or rectangle shapes up to 50 units. Over 50 units the sub-groups may be placed organically (The Sphere; De Chiara, 1984). The secrecy distances in the site can be obtained from Time Saver Standards. Also the location of the units according to roads is important, in 45 deg. Location, more space is saved. Other important facts that shape the design of the building-site of temporary living are the personal or public open space distribution and the location of the recreational and social service sites that shouldn't be kept apart from the units. (Abeles, Schwartz & Associates- Vol. 4, 1976)

The disaster people show a consuming status until the psychological & social depression ends, so the first thing to be concerned in the design is the services of the site and the units. Beyond this, in the site, the temporary health clinics, banks, public telephones and schools should better be placed. Temporary public transportation lines should serve the site or special transportation vehicles should be maintained for the defined site. (Eyüce, 1978; JICA, 1999)

After the Kocaeli experience, it's obvious that a temporary warehouse is needed in the temporary building-site where the disaster people can preserve their saved belongings, which they do not need while the temporary living period. The overlapping storage systems tried to be done in the units of 1999 Düzce earthquake's temporary units weren't secure at all. The enlargement of the unit for storage of the belongings wouldn't be logical as well; so extra storage units must exist in the project.

4.2.2. The Optimum Living Conditions Required in "Temporary Post-Disaster Housing Unit"

The temporary post-disaster housing units are not preferred as comfortable as the permanent post-disaster housing units; because if they would be as comfortable as those, people would not to leave the temporary ones and move. However, the temporary ones must obtain the standard optimum living conditions.

4.2.2.1. The Spatial Characteristics of the "Temporary Post-Disaster Housing Unit"

In the units, different functions should be placed in different spaces. The spaces that should be defined in a temp post-disaster housing unit are living area, kitchen, bathroom and sleeping areas. All these spaces should be kept in minimum dimensions.

In a standard unit; the kitchen is mostly a part of the living place and the living room can be converted into a sleeping area at nights by the help of the convertible furniture systems, the eating spaces can be placed in between the kitchen and living room in order not to loose space, the bathrooms are naturally separated spaces placed next to the sleeping areas. A separated sleeping area is better to be designed for parents. If the building-site has a laundry facility, no washing machine is needed to be placed. In the entrance of the house an outdoor terrace can be placed especially in hot-climates where half-open spaces are needed. The outdoor terrace is also an in between space (a semi-private space) where the house has a transition to outdoor space.

4.2.2.2. The Dimensional Requirements for a "Temporary Post-Disaster Housing Unit"

The area of the temporary ones should be smaller compared to permanent post-disaster housing units, but in this small area all the minimum standard function areas should be maintained. The minimum area needs for each different space vary between studies and can be followed in the master thesis study of Baradan.

As stated in the study mentioned above, the total area of a temporary post-disaster housing unit differs according to the number of people living, so it's better to design 2 or 3 different types of housing units or units that have a system suitable for enlargement in order to oppose the needs of the various families. In most of the studies, the minimum circulation area is added to the areas needed for each member of the family for finding the total area of a temporary post-disaster housing unit.

4.2.2.3. The Comfort Conditions Required in a "Temporary Post-Disaster Housing Unit"

The climatic, visual and sound comfort conditions are required in a temporary post-disaster housing unit. The unhealthy materials shouldn't be used in the building and the services should be maintained well in the house in order to have the standard physical conditions and in order not to cause any psychological harm, each space in the house should be big enough. (Bonnefoy & Braubach, 2001)

4.2.2.3.1. The Climatic Comfort Conditions

Heat Comfort Conditions

The heat comfort conditions in a house are obtained in between 18-27 °C when 50% relative humidity is kept in mind. If the temperature of a place is lower than 12°C, this can cause health problems. The optimum temperatures for living room is 21°C, for kitchen, circulation areas and bathrooms 16°C and for sleeping spaces 18°C. the maximum temperature in the house shouldn't be over 37°C. (İmamoğlu, 1994; Bonnefoy & Braubach, 2001; Cimcoz, 1985)

In countries like Turkey that has many different climate conditions in, there may be no heating system suitable for each region, so the heat control should mostly be controlled by the outdoor covering elements in the temporary post-disaster housing units. The minimum λ s of the materials should be; 0.8 W/m °C if the flooring touches the ground, 0.5 W/m °C for the exterior walls, 1.5 W/m °C for flat roofs and 1.0 W/m °C for standard roofs (Songür, 2000). The materials that obtain these conditions without any insulation are wooden, plastic based or composite materials. (Ervan, 1995; Oğulata, 1995)

Insulation layers are needed for most of the applications. The insulation layers should be installed in the right places with accurate thicknesses for good solutions. The insulation elements should be chosen from light, strong and biologically, chemically and physically resistant to outer affects. If the material also resists humidity there would be no need for extra insulation layers. The insulation materials that mostly obtain these conditions are glass-wool slab and polyurethane hard foam (Ervan, 1995). Glass-wool slab is more resistant to fire and acid while polyurethane foam is more resistant to strokes and suitable to adapt on the demountable system elements. The fire resistance of the polyurethane foam can be held by covering it with fire-resistant outdoor covering elements. (Ervan, 1995)

To avoid heat-bridges in the outer coating elements and heat transfer between indoor-outdoor, the detailing of the building, window areas and the location of the building have extra importance.

Ventilation Conditions

The air circulation in the houses has a great importance. The air circulation rate in the temporary post-disaster housing unit should be 8-10 m/minute in wintertime and 13-27 m/minute in summer time. For this reason the windows should be placed facing each other (Ersoy, 1994; Güler, 1994). The needed air circulation rate per person is calculated to be 4 m^3/hour in the master thesis of D. Songür. It should be kept in mind that plastic based materials increase the air circulation needs.

Prevention of Humidity

Humidity in the walls affects the health of the people and also it may cause damage in the elements of the unit. In order to obtain the reuse of the unit humidity should be avoided by insulation. Water should also be insulated for avoiding corrosion and material damages.

For keeping a dry place and avoiding humidity and ground water, the temporary post-disaster housing unit can be raised over footing elements. The detailing at -the connection points of foundation to house- has a great importance in keeping the place away from water or humid. The joint pastes and joint fillings, which are made in between the modular elements have extra importance in water and boil insulation. Insulation can be done by a layer of water-resistant material or by the covering of the outdoor elements with a water-resistant chemical paint or so. The water amount and pressure of the weather conditions applie should be known to choose the right insulation materials.

4.2.2.3.2. The Optical Comfort Conditions

The most important thing in obtaining the best visual comfort conditions is daylight. The houses should keep daylight at least for two hours in a day even in wintertime. The temp p-d h units are mostly single storey buildings that allow daylight to reach inside. At points where daylight can't reach and for nighttime, artificial lighting should be used for obtaining the standard lighting. (Güler, 1994)

4.2.2.3.3. The Sound Comfort Conditions

In standard houses sound pollution should not pass 50dB and in the sleeping areas it should not pass 30 dB. The window and door replacement details, directly affects the sound transfer. For temporary post-disaster housing units, extra sound insulation materials are not needed; it should be kept in mind that the heat insulation layers are also effective in sound insulation. (Ervan, 1995)

4.2.2.4. The Structural Properties Required for "Temporary Post-Disaster Housing Unit"

4.2.2.4.1. Demount Ability (Availability for Reuse)

The most important characteristic of a temp post-disaster housing unit should be the availability for reuse. After the disaster people pass to permanent units, the temporary houses should be unfixed and stocked to be reused in another disaster occasion. In order to reuse the unit, the connection details should be solved mechanically; by clenching, pressing the joints, screwing or bolting. (Bazoğlu, 1981)

Demount ability can be obtained with wood and metal elements better compared to concrete elements (Ervan, 1995). Also for unfixing and removing the whole temporary units from the site without damage, the houses must not have a constant relation with the ground like conventional concrete slab on the ground or conventional base elements. For avoiding damages and ruptures on the house, the utilization period should be minimized and the needs of the people should be thought completely in the design of the house. When the house is damaged, the damaged elements should easily be removed and changed. If the people need any enlargement in the house, by adding extra elements, the housing unit should be enlarged easily, so no damages on the system would occur. All the temporary units should be pulled apart and fixed before stocking for reuse in the temporary building-site or in the stocking place after transportation.

4.2.2.4.2. Easy and Fast Montage

The montage of all the temporary post-disaster housing units is preferred to be finished at most in 12 days (Sey, 1999; Songür, 2000). In my project, it's proposed to do the montage of the urgent units possible in at most 48 hours and all the process to be finished in the emergency period.

For easy and fast montage; inscription papers that has application photos and drawings, may be added in the packages. The number of elements used in the built-up of the house can be decreased. The weight of the components should be kept in minimum (100-150 kg is the maximum in standards), the elements can be chosen as modular and standard in size with different variations for openings. Simple equipment use and simple detailing should be done for the buildings to be worked out by unqualified workmanship. Two same sided panels are better to be used for not to cause any mistakes in fast montage. If the joint elements are kept on the components, the places of the elements wouldn't be blended; also if the same joint element is used in each connection, the process again will be faster.

For fast erection of the indoor elements, the montage locations of the wet-space elements (lavatory, closet, basin etc.) should be defined on the panels and all the service channels should be pre-prepared. Modular coordination of the system also helps the system to be worked out faster. For demounting and storing of all the elements in the unit, the order of applications has great importance.

4.2.2.4.3. Fast Production

In disaster management, the ideal method is not producing the temporary units after the earthquake. Especially in countries that always face disaster occasions like Turkey, the temporary post-disaster housing units should be produced and stocked before the occasions. The number of temporary unit stocks is stated as 2000 according to scientists. (Sey, 1999b)

To produce feasible and continuous production, local and industrialized technologies and materials should be preferred. The fast production also depends on the independence of the temporary house production sector from others and the fast shaping of the materials (Ervan, 1995).

4.2.2.4.4. Easy Transportation

The transportation of the temporary post-disaster housing units is made in two steps. First step is the transportation from the production center to the storage center and the second one is from storage center to the building site. The first step doesn't need hurry while the second needs to be done in a rush.

For fast transportation of the units, the distance in between the storage and building sites should be kept in minimum. The transportation vehicles have great importance in the fast transportation. The vehicles should be chosen as the biggest and fastest while the unit or element packages as the smallest and lightest to carry many units at once. The package organization and size for fitting should be thought according to the size of the transportation vehicle.

Table 4.1 The maximum sizes of the Internal road vehicles in Turkey

	Width	Length	Height	Weight
Exterior Dimensions	2,5 m	12,2 m	2,6 m	26,5 ton
Interior Dimensions	2,4 m	12,0 m	2,4 m	26,5 ton

According to these vehicle sizes, the package sizes shouldn't be over 2.4x4x2.4m.

4.2.2.4.5. Easy Stocking

All the produced elements should be stocked in good conditions until they're needed. For easy transportation of the elements and reuse, packaging and storing are the most important facts.

The size of the packages should be kept in minimum. Otherwise, the big sized elements can be damaged while transportation and extra equipment would be needed to fix the packages as well. The service elements should also be stocked in the same numbers with the units, if possible in the unit packages. For avoiding the loss of space in stocking, in packaging, linear elements must have been preferred and modulation should be done for the panel elements.

The materials of the packages should be strong enough to bear the strokes while moving. Packages can be made out of both soft and tough materials; in both cases the possibility of using the package material in the temporary system solves the problem of stocking and extra transportation weight of the package elements.

In storage, also the material characteristics of the units have importance. For example, concrete systems can even be kept in outdoor conditions while wood even has difficulties to be kept in indoor spaces. How to store each element should be thought before. Even tents should be kept in air-conditioned indoor spaces, without ventilation they can only be kept for two years.

4.2.2.4.6. Earthquake, Wind and Fire Resistant

"Temporary post-disaster housing units" are the units that are designed to be used after the disasters by the psychologically affected people. The structure of the construction system and the look of the housing units should be convenient for the victims of the disasters to live in. *"After the Afyon earthquake the pneumatic igloos that were used as the -temporary post-disaster housing units- hadn't been appropriated by the victims, because of their unfamiliar looks"* (Sey, 2004)

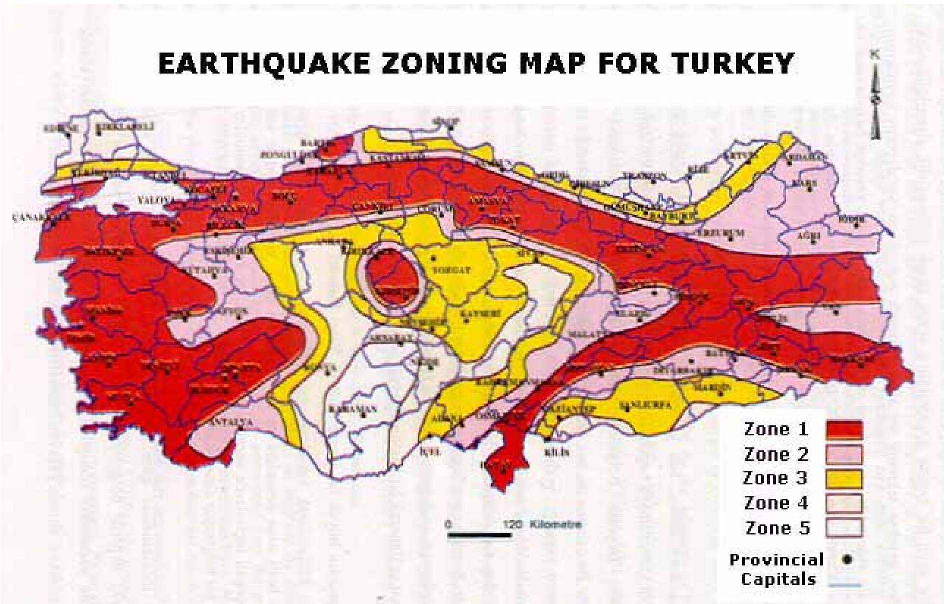


Figure 4.1 Earthquake zone map for Turkey

Especially when the people are the victims of earthquakes -which are one of the main disasters of Turkey that can mainly be demolishing in the urban areas-, the people want to be sure that the structure they will go in will be safe. The following small earthquakes make the victims dizzy and it may cause them to leave the temporary units if they don't convince with the safety of the structures. To prove the safety of the structure in case of earthquakes and in case of other climatic disasters (wind) should be another goal in the design of the "temporary post-disaster housing units". The structure should be fire-resistant, if the fire affects some of the materials used in the design, the fire precautions must be maximized.

4.2.2.5. The Durability Conditions Required for a "Temporary Post-Disaster Housing Unit"

The temporary post-disaster housing unit should be resistant and adaptable for different ground and climate conditions. The house should resist rainy, snowy, hot or cold weather conditions and high humid environments and should at least be used in 3 different disaster occasions and should exist for 2 years without any damage. The utilization life of the unit should be minimum 6 years and stock life 5 years (Songür, 2000; Emery, 1981).

It's almost impossible to design a temporary post-disaster housing unit which is suitable for all the places on earth without making some differences in at least some parts of the project.

4.2.2.6. The Resistance of the Covering Elements Required for a "Temporary Post-Disaster Housing Unit"

The most important fact that makes the unit to be long lasting is the resistance of the outer elements. The ability of resisting strokes, fire, chemical affects, termites and bugs defines the resistance of the material. For keeping the rain away from the unit, the covering material should be chosen as rain may slip on. The covering element can be chosen of slippery material or a film layer can be placed on the surface of the covering. As mentioned before the connections in between the panels should be filled with different materials to avoid wind and water to sneak inside.

According to the study of Baradan, the most resistant way of using materials is the composite use. The reason has been stated to be the variation of the materials causes the variation of resistances. The disadvantages of some materials can be prevented by precautions. Like the heat transfer bridges happening on the exterior surfaces should be solved by insulation or by detailing.

4.2.2.7. The Flexibility and Variability of a "Temporary Post-Disaster Housing Unit"

The flexibility can be held by three ways in a temporary post-disaster housing unit;

- Enlargement of the smallest unit on an ax.
- Enlargement of the smallest unit on two axes.
- If the smallest unit cannot be enlarged, it should be designed suitable for other extra organizations. (Ervan, 1995)

The variability in the design of the temporary post-disaster housing units is a must, because the family member numbers vary. So more space needs may occur, the variability and/or flexibility have to be thought and considered in the design process.

This is a major characteristics of a temporary post-disaster housing unit and differentiates it from the general permanent house design types.

4.3. A "Temporary Post-Disaster Housing Unit" Project with LGSF System; Concept, Drawings and Presentation

4.3.1. Concept (The Scenario)

CONCEPT: TEMPORARY POST-DISASTER HOUSING PROJECT PROCESS PLAN FOR TURKEY

In Turkey, every year different disasters have been faced in different regions. For example; floods, landslides, hurricanes, storms and earthquakes. The poor quality of construction and lack of design consciousness on disasters (like earthquake resistant design) cause many of the building stock of Turkey to demolish each year. According to Prof. Dr. Yıldız Sey, each year approximately 1000 temporary post-disaster house should be produced for disaster occasions in Turkey. (2004)

In this section, in the light of the previous part (the qualifications defined for a post-disaster house) a new post-disaster housing project study will be explained for Turkey conditions.

The system contains temporary post-disaster housing units for 1000 people. The prefabricated system elements are packaged with the outdoor covering elements of the housing system and these packages would be stocked in four different points on Turkey ready to be transported. The four storage plots have been chosen according to their distance legs to every region of Turkey. These plots have been located to central points on the main (traffic) road axes to maintain easy transportation which is highway transportation in Turkey.

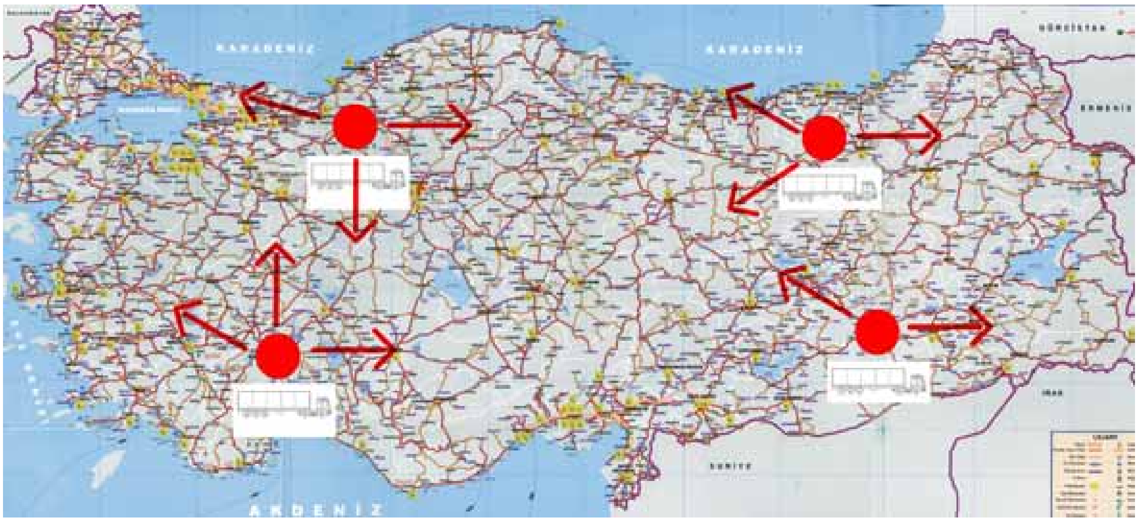


Figure 4.2 Storage points for emergency departures in case of disaster

In each storage point approximately 8 housing elements containing 40 to 80 variously sized temporary post-disaster housing units have been stored. In an emergency occasion, from the nearest storage point to the disaster site, the first 4 housing elements would be carried. A housing element can be packed into 16 boxes (various sized) and can be carried by two big trucks. Four trucks should carry the two housing elements and an extra truck would be used for the carriage of the base elements. A truck can hold all the base elements of the eight units.

The site of the temporary housing should be examined and defined before the disaster occasions occur. The central government can cooperate with the local governments in order to decide on the exact place suitable for a temporary living site. The qualifications of the temporary building site are defined in Section 4.2.1. The infrastructure elements should be obtained by the local governments for the short periods (limited by one year). The sewer system can be solved by cesspools system and the storage elements of the system would be emptied by vehicles, which would be an easy system. The clean water can be obtained from a water supply nearby, if there isn't any natural water supply around the site, the clean water can be carried to a water tank that should be placed on a higher point for easy distribution of water. The site should be chosen nearby the urban site for different reasons so the electricity may easily be maintained.

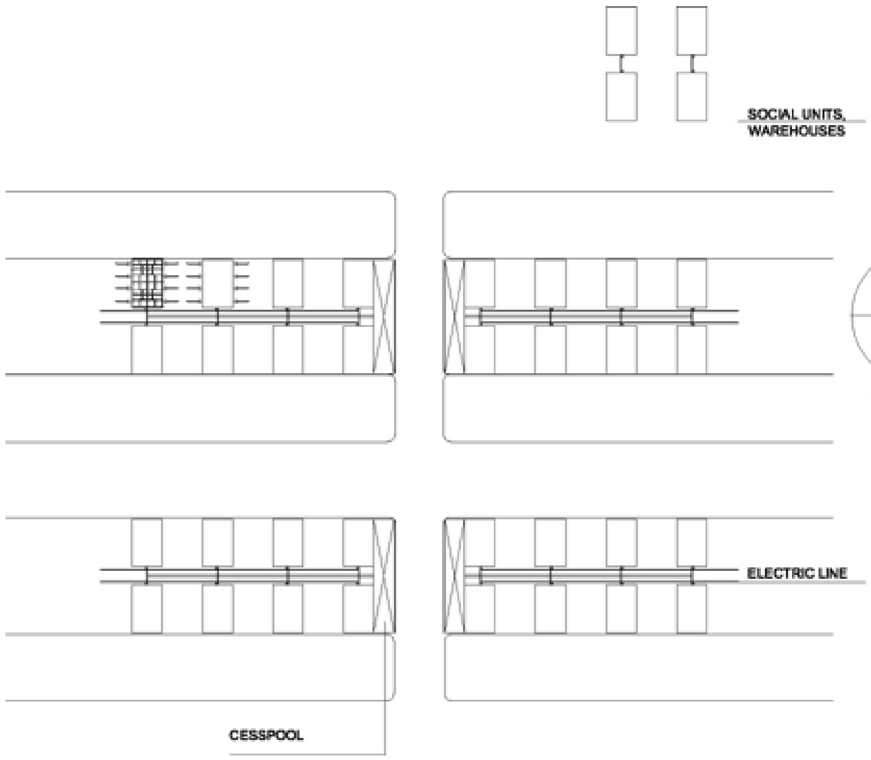


Figure 4.3 Site plan analysis of the proposed project

On site, first the infrastructural facilities should start to be structured while the first four trucks carrying the two house elements and base element truck are on the way.

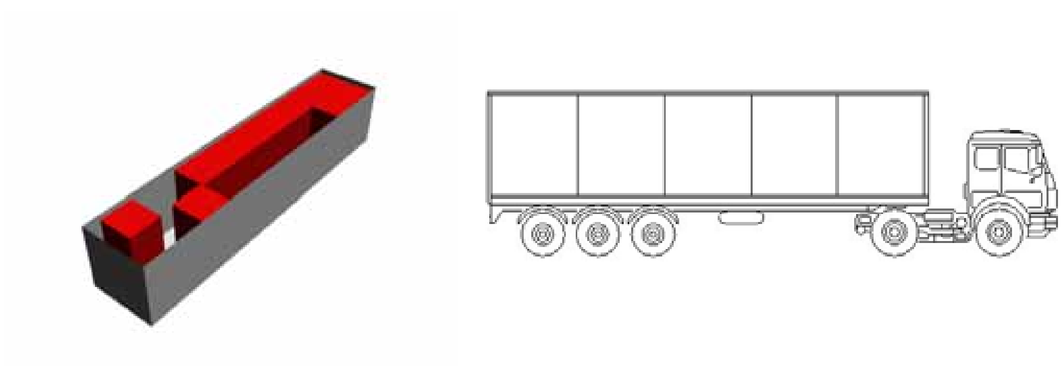


Figure 4.4 Transportation of boxes with trucks

The base elements are placed to the 15 cm dig wholes. The wholes for the base elements can be dig while the infrastructural elements are placed. When the base elements arrive to the temporary building site, they are placed by the help of a crane. Each rectangular base element is 40/30/100 cm sized and weighs approximately 240 kilograms.

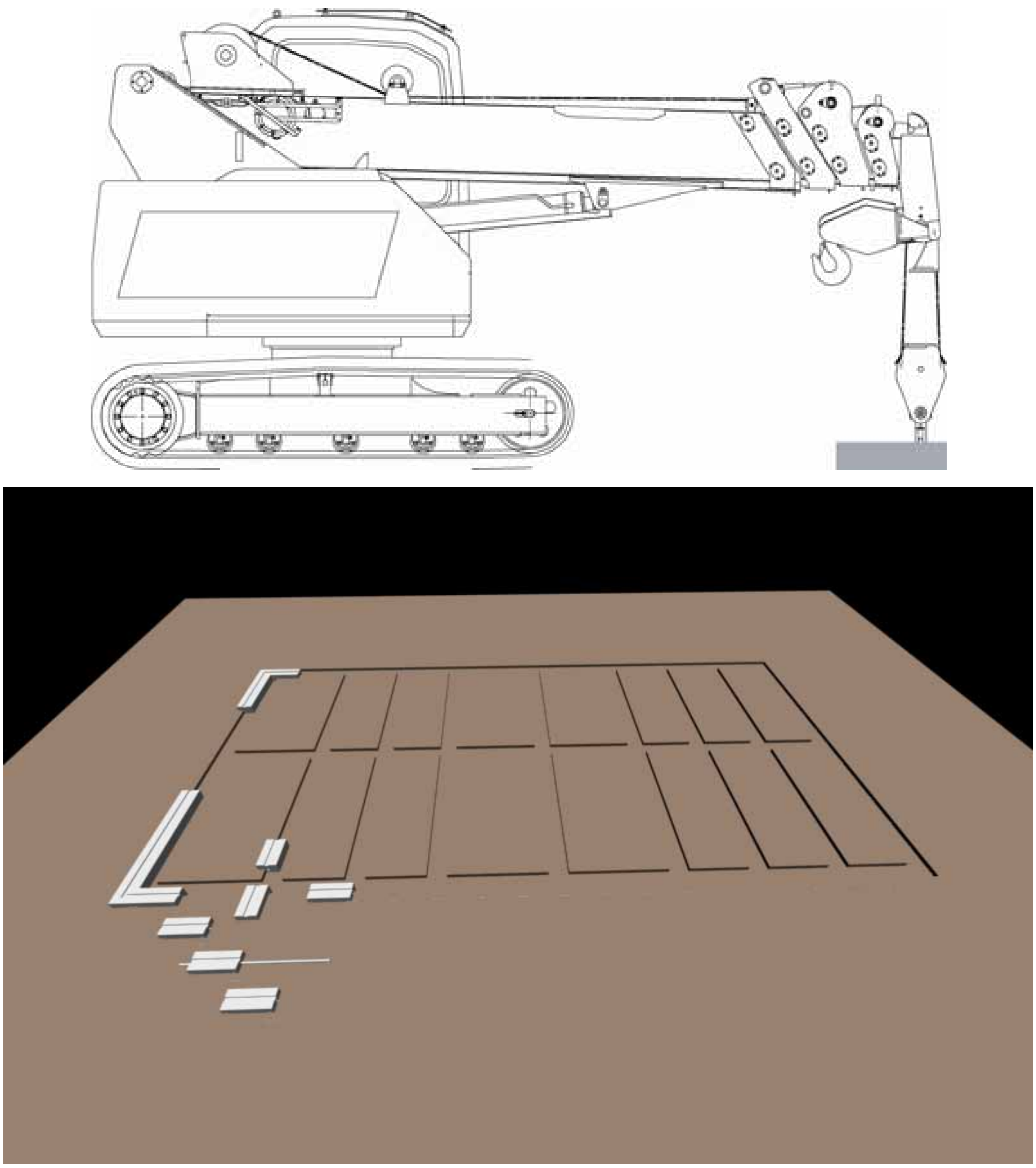


Figure 4.5 The application of the modular concrete foundation elements with crane

Then, the elements are locked to each other by pre-designed steel joint elements and to maintain a more stable basement system, the elements are stretched and joined by pre-stressing wires.

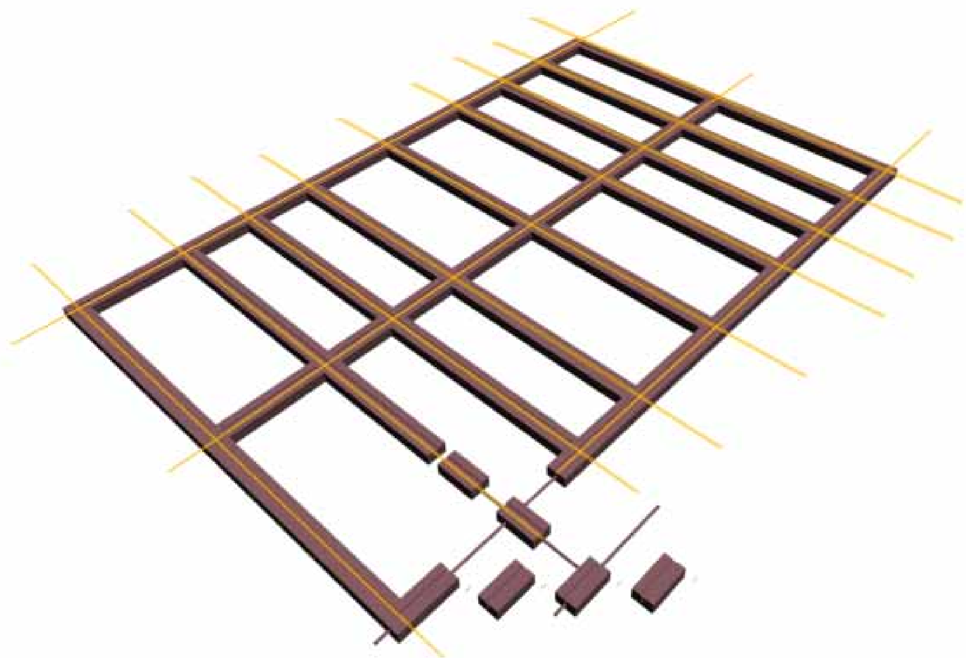


Figure 4.6 Pre-stressed cable organization in the foundation plan

When the other four trucks arrive, the crane is again used to carry the packaged elements. After this step there will be no need for an extra vehicle or equipment to do rest of the building process. All the structural panels and the covering elements are designed to be carried by only one person, in different points at most three people can carry on the fast build-up process. When the boxes are opened there will be guideline sheets attached inside the box and the joint points will be painted in different colors so in urgent cases any unqualified workmen can build the system as in the examples of other LGSF housing packages in America and in Australia.

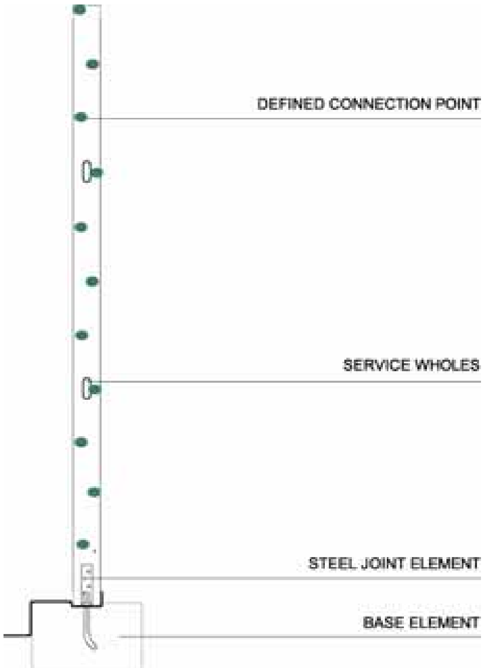


Figure 4.7 Pre-designed wall panels with painted connection points

The next step should be the replacement of the structural wall panels. The LGSF wall panels each weigh around 20 kg. They should be joined to the basement elements by anchorage of the steel part. The wall panels should also be attached to each other to maintain the stability of the LGSF system. All the LGSF material attachments are done with self-tapping screws by the help of a screwing gun, so the montage becomes very fast. Removing the self-drilling screws is also easy and fast compared to bolting work.

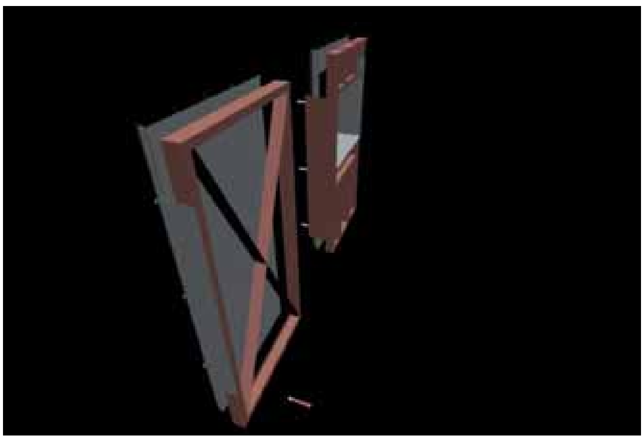


Figure 4.8 Wall panel-outdoor coverage element connection detail

The walls can be covered by the polystyrene trapezoid board panels (the coverage element), after the technical pipes are placed through the wall system. The trapezoid panels are attached to the wall panels as shown in Figure 4.8. Each trapezoid panel weighs around 7.5 to 11 kg according to its size. These panels are also the package elements of the boxes stored. The secondary elements combine the outer skin to the panels and there's a void space left between the two skins to maintain a better insulation. Again the secondary joint element is attached to the LGSF panels with screws, but the joint of the secondary elements to the coverage elements have been done by adjustable bolts.

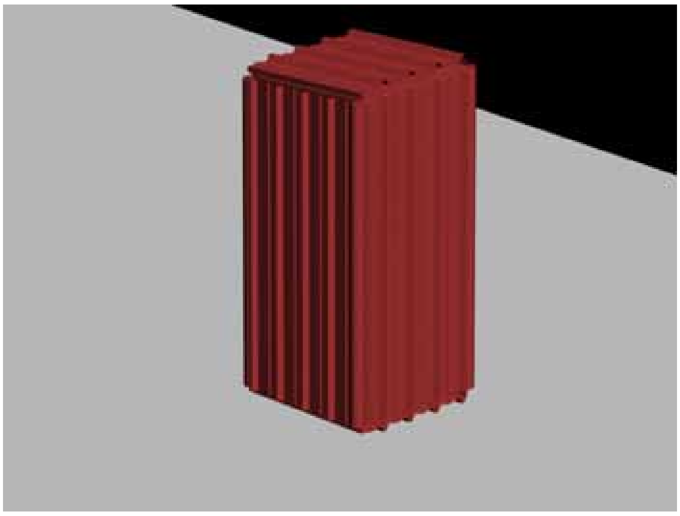


Figure 4.9 Typical package box of prefabricated elements

The floor (ground) elements are also unpacked and joined to each other by steel joint elements with the help of bolts. The floor system is located on top of the base elements with anchorage elements; technical pipes are located under the floor system over the compacted ground. The floor grid system should be covered with OSB panels, which help the stability of the flooring. It is better to build up the roof, before putting up the interior covering elements and floor coverings.

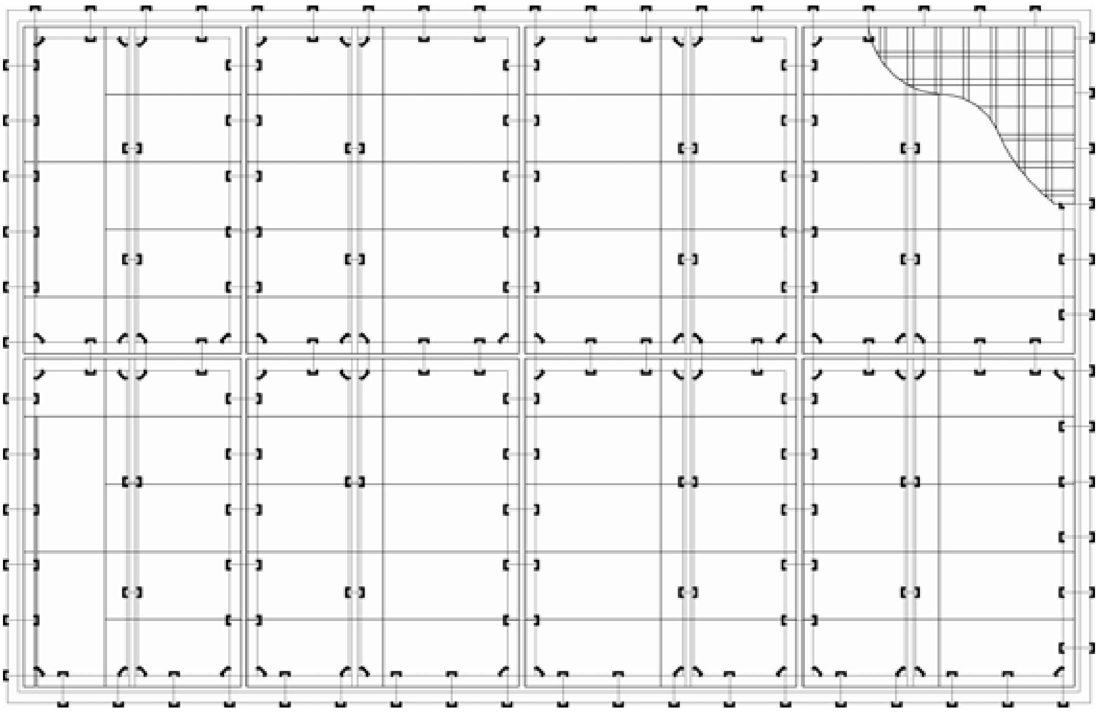


Figure 4.10 Floor system plan

The roof covering elements are the best to be used as the main package elements with their definite sizes. The roof does not have a truss system; the headers of the LGSF walls are strong enough to carry the cold-formed C profiles placed over for the roof system. The rafters are placed over the profile system. The rafters are also made of cold-formed material, so the roof elements are also light and easy to be carried, but in the roof building process, a ladder is needed. The C profiles used in the roof system are the only continuous long profiles, which are 600cm. The rafters (omega profiles) are cut as 100cm in length. Over the grid of profiles and rafters on the roof, the OSB panels are placed. The OSB panels helps to increase the stability of the roof system. This layer is covered by water balancing insulation layer and the polystyrene trapezoid board panels are placed carefully at the top.

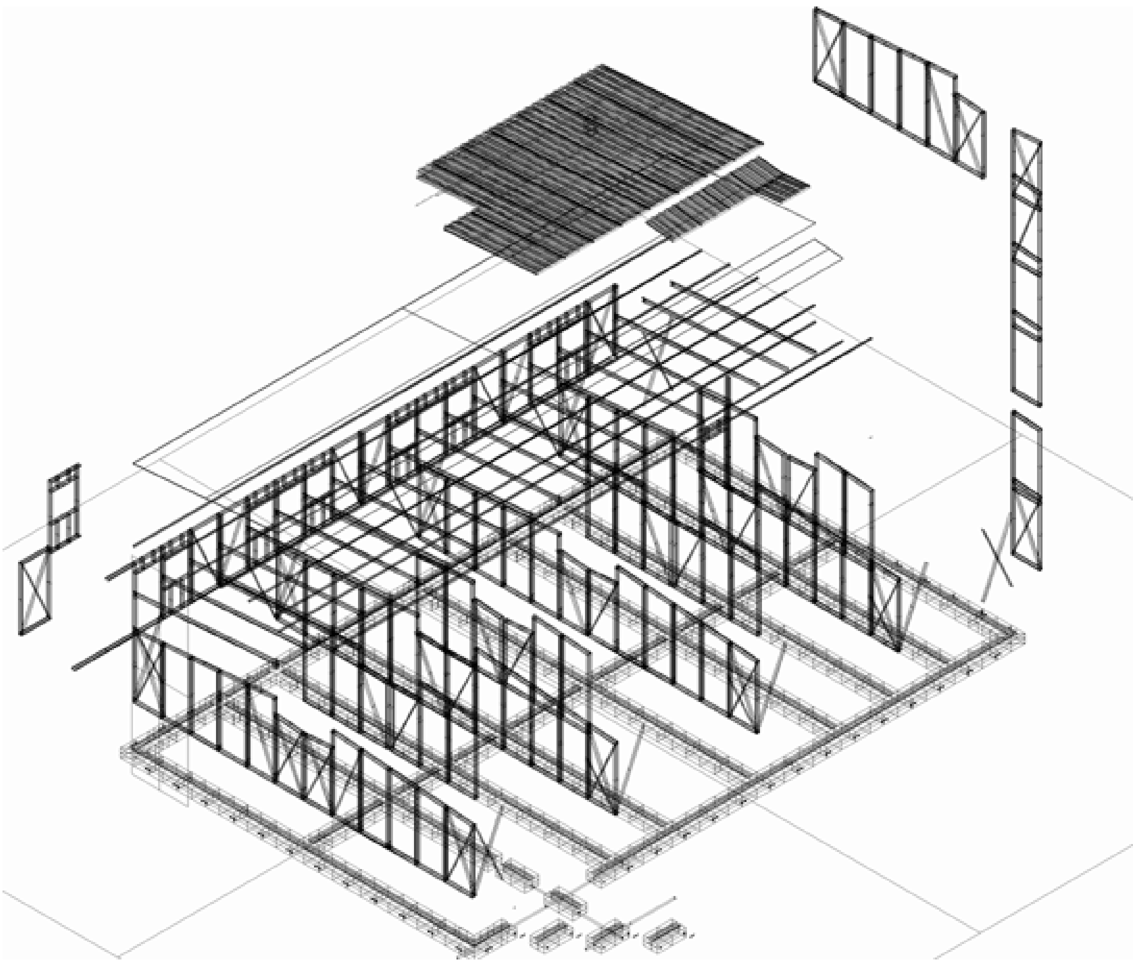


Figure 4.11 General structure plan showing main steps

The interior covering elements (plaster boards and linoleum) are the last parts to be attached to the system.

The first 8 trucks should arrive to the temporary building site in the first day and the first two housing elements which contain 16 housing units should be finished in two days, if the site can be compacted and the places of the houses can be dig within the first day of the disaster, the dormitory units (future housing units) have been made ready in the second day of the disaster. While the workmen are building these units, the infrastructural facilities should be done or recovered. The transportation of the other units would be completed within the following days of disaster from the elements stored in other storage points. The four trucks should return back to be loaded for the other 2 houses while the other trucks are going on the way to bring the elements from different points. 20 trucks should work all together on this project, four to carry the housing units and one to carry the basement elements at each different storage point. Each 4-group truck should do 4 tours to the site to take all the elements to the site. This process would take at least a week, but this wouldn't cause a problem if the first 4 houses can be built within 2 to 4 days. These housing units would be used as dormitory units until the whole project is completed. After it is completed, the victims are placed to their housing units and the dormitory units can be converted into public spaces like laundry rooms, warehouse or shopping areas. These units are also suitable to be converted into standard housing units. According to the needs they can be used as a public element (shop) or a private housing element.

The standard housing blocks which are explained in detail with the drawings in the next section, are 224 m2 interior spaced. They are planned to be converted into 8 housing units (2 for 2-3, 6 for 4-5 people) or 4 units (2 for 6-7 and 2 for 8-9 people). These housing units are suitable for extensions and conversions as shown in the drawings in the following pages.

DEVELOPMENT PLAN OF THE UNITS

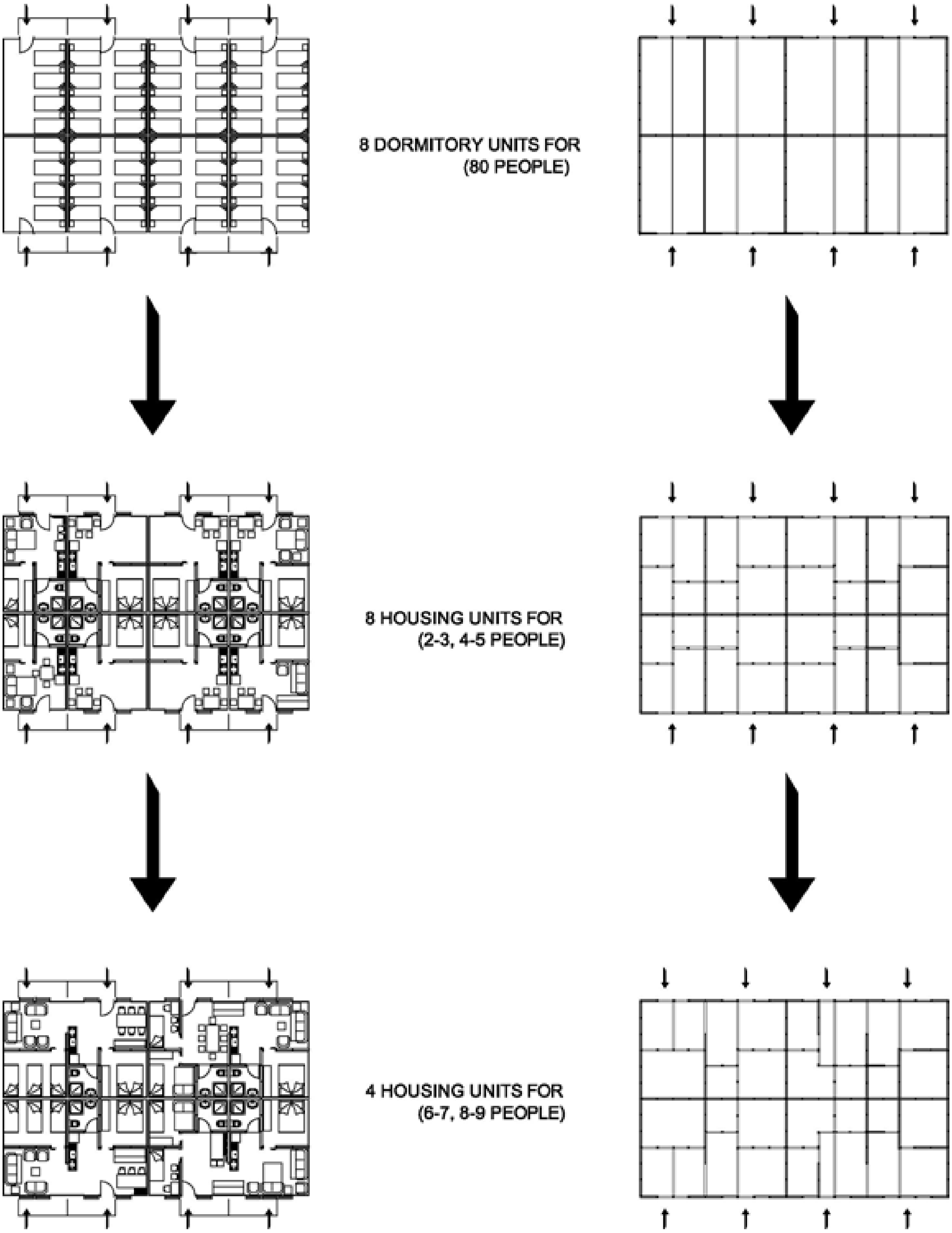


Figure 4.12 Development plan for the units

EXTENSION PLAN FOR THE UNITS

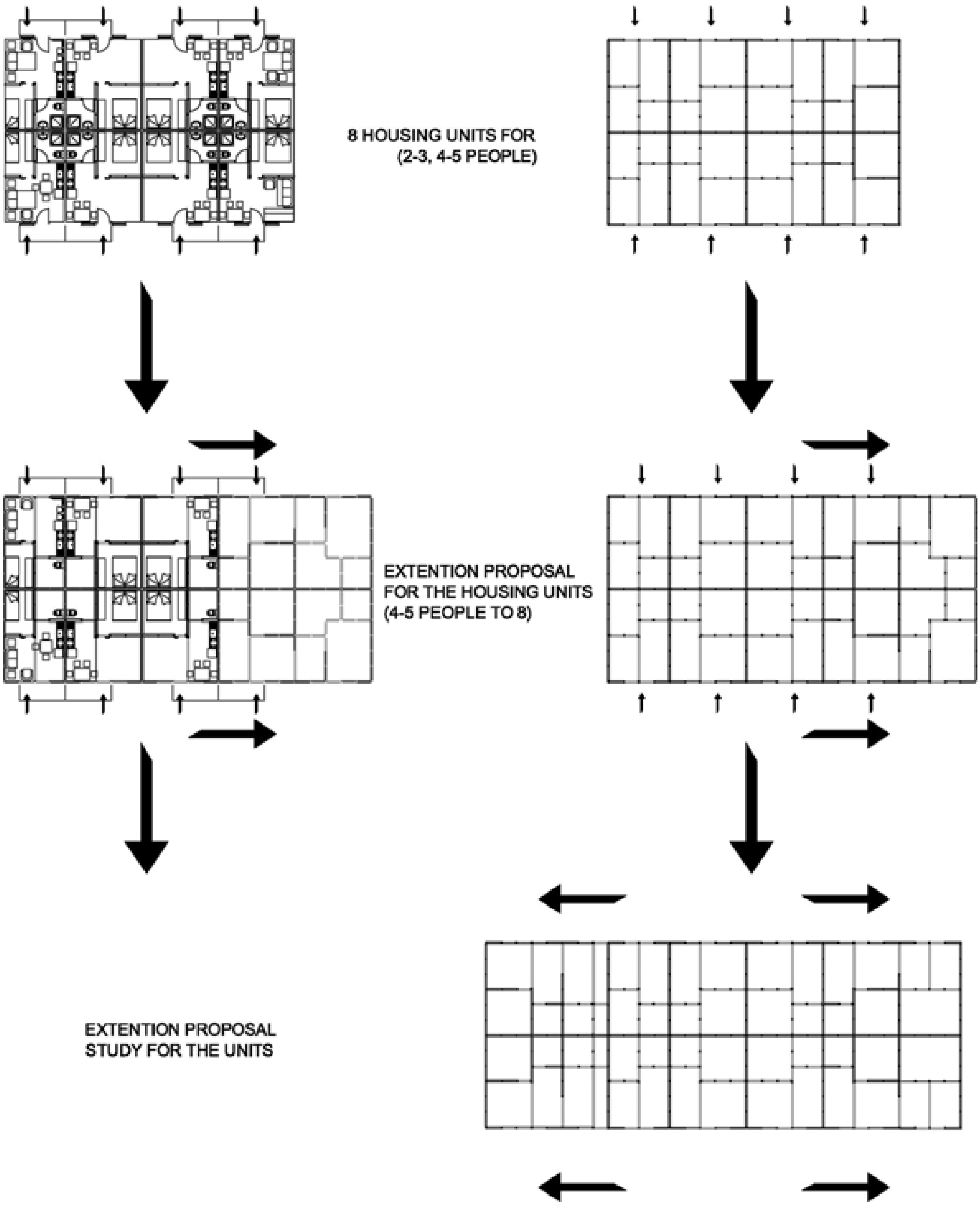
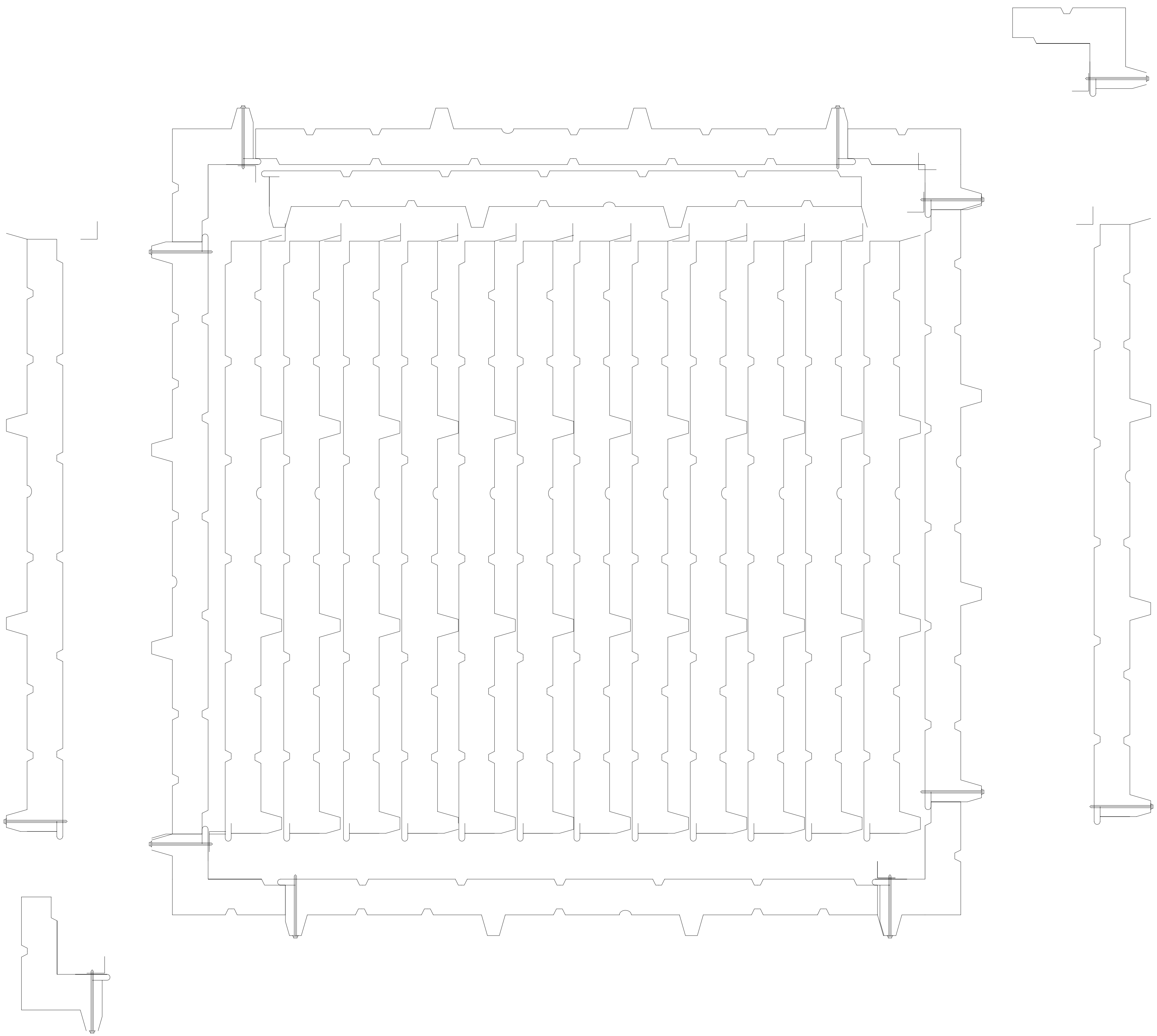


Figure 4.13 Extension plan for the units



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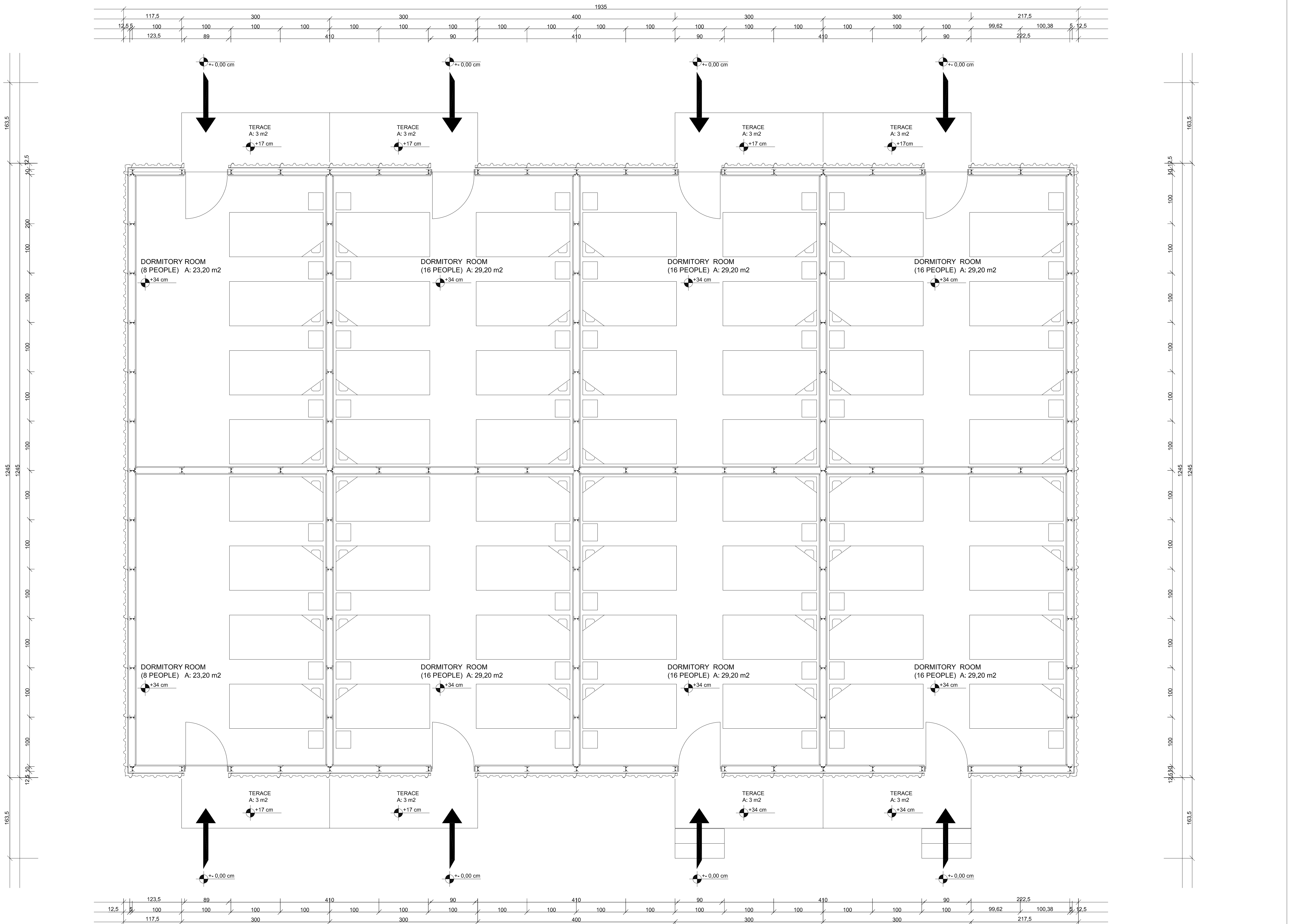
TYPICAL BOX DESIGN OF THE PACKAGE SYSTEM



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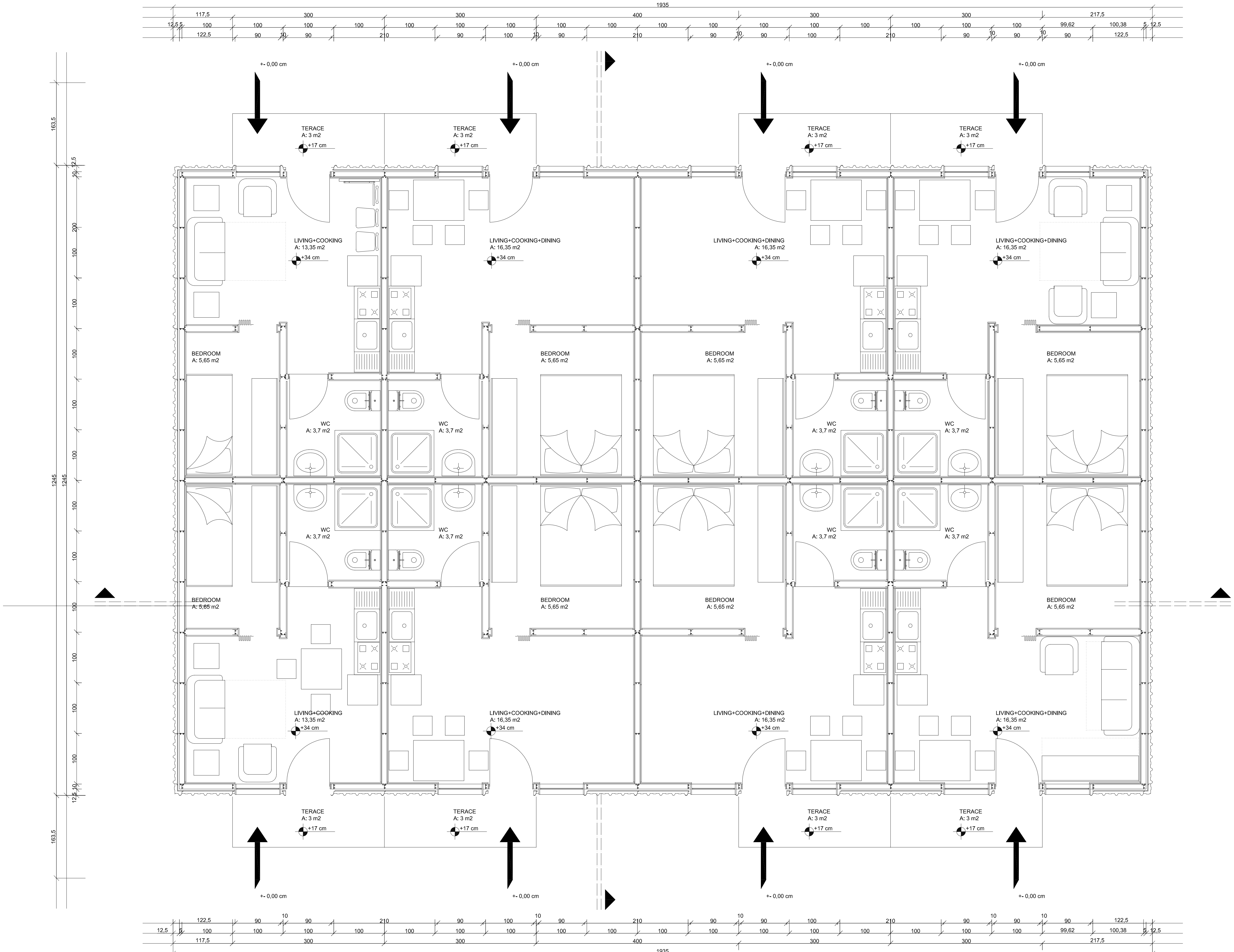
DORMITORY FOR (8) & FOR (16) PEOPLE
HOUSE FOR 112 PEOPLE



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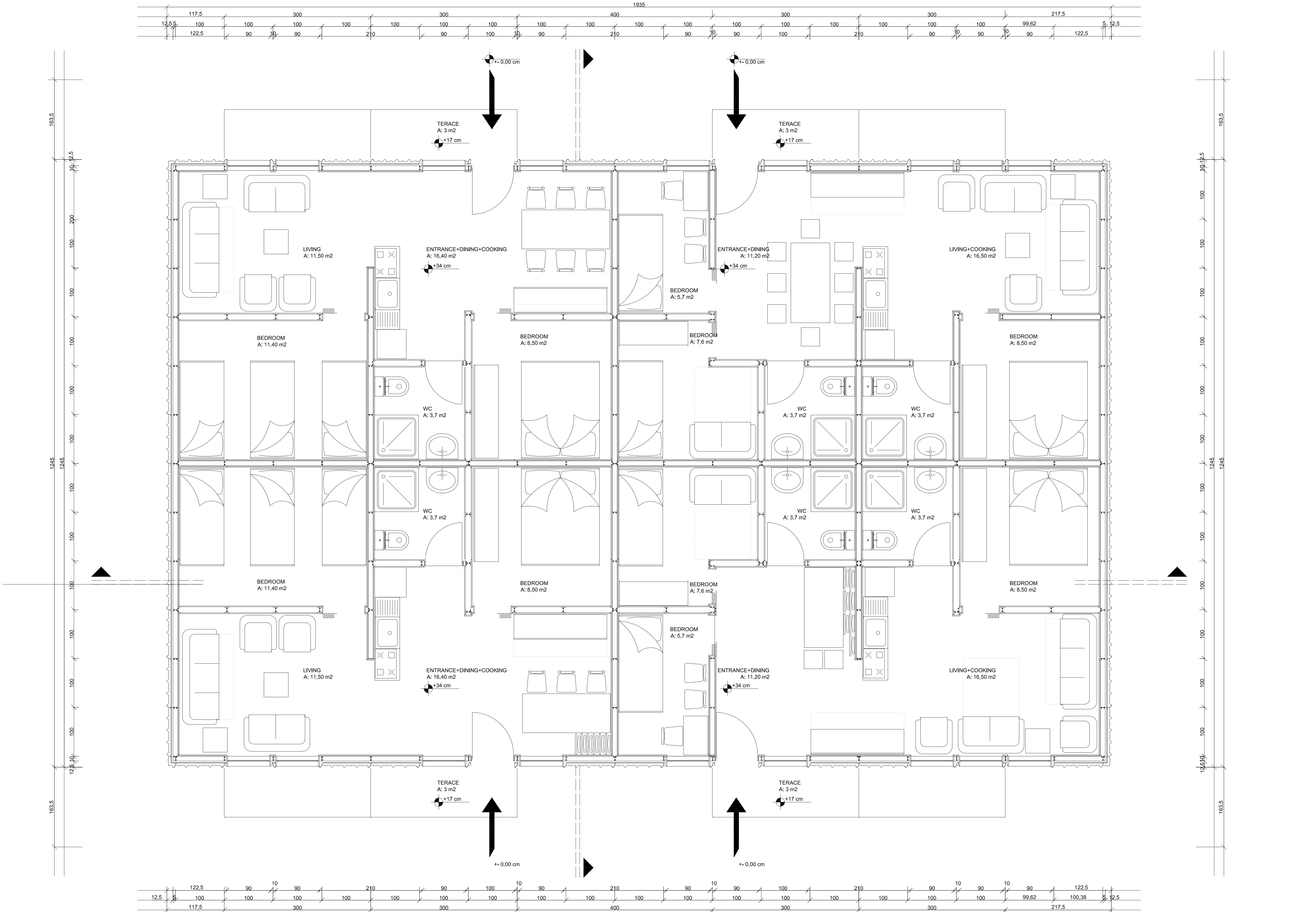
HOUSE FOR 30 PEOPLE



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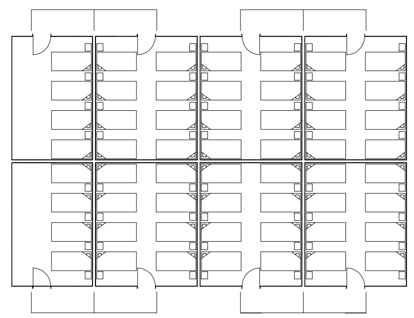
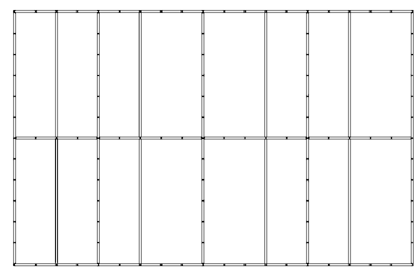
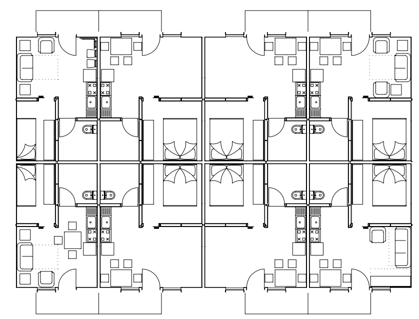
HOUSE FOR 30 PEOPLE



8 DORMITORY UNITS FOR
(80 PEOPLE)





8 HOUSING UNITS FOR
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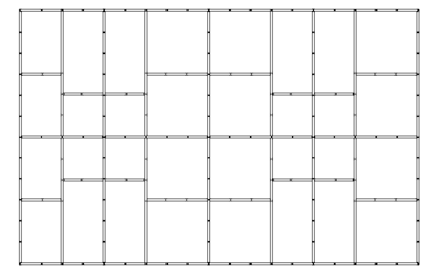
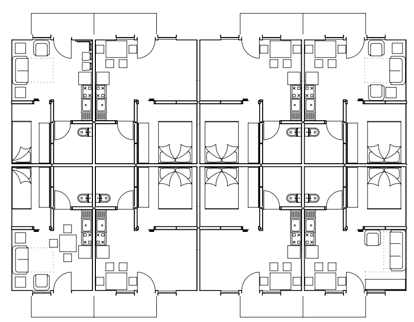
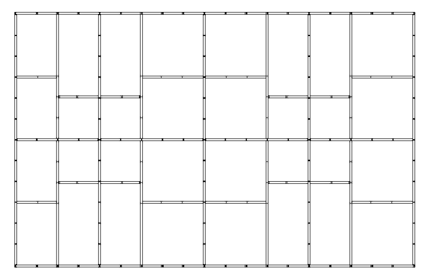
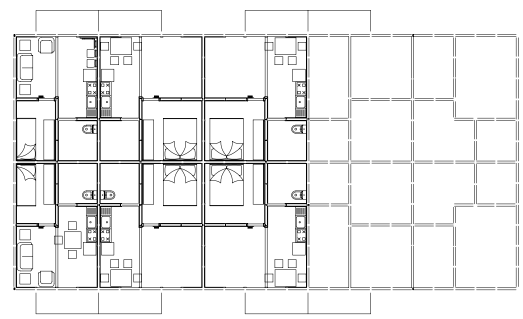


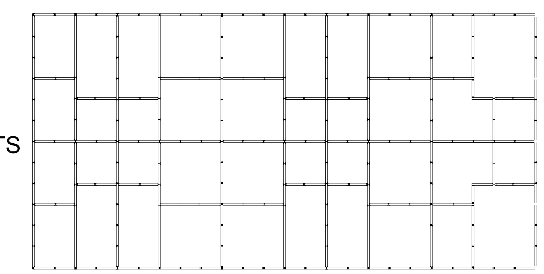


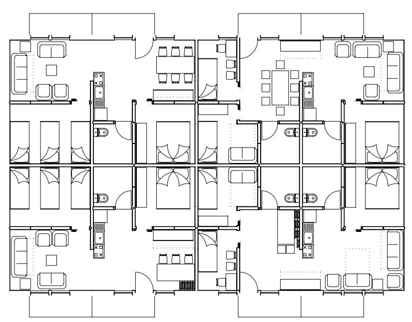
8 HOUSING UNITS FOR
(2-3, 4-5 PEOPLE)



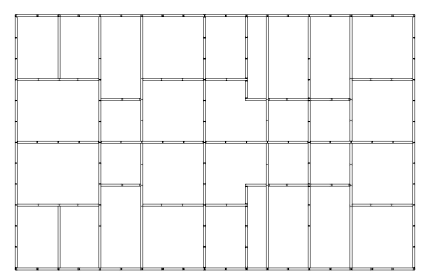


EXTENTION PROPOSAL
FOR THE HOUSING UNITS
(4-5 PEOPLE TO 8)

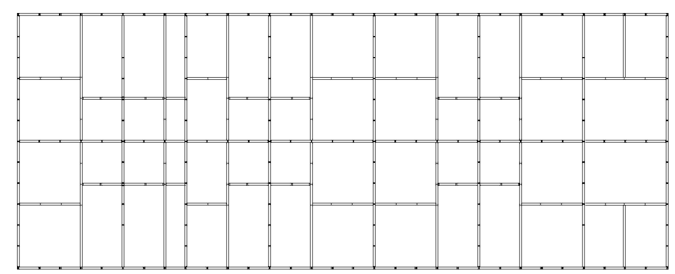




4 HOUSING UNITS FOR
(6-7, 8-9 PEOPLE)



EXTENTION PROPOSAL
STUDY FOR THE UNITS



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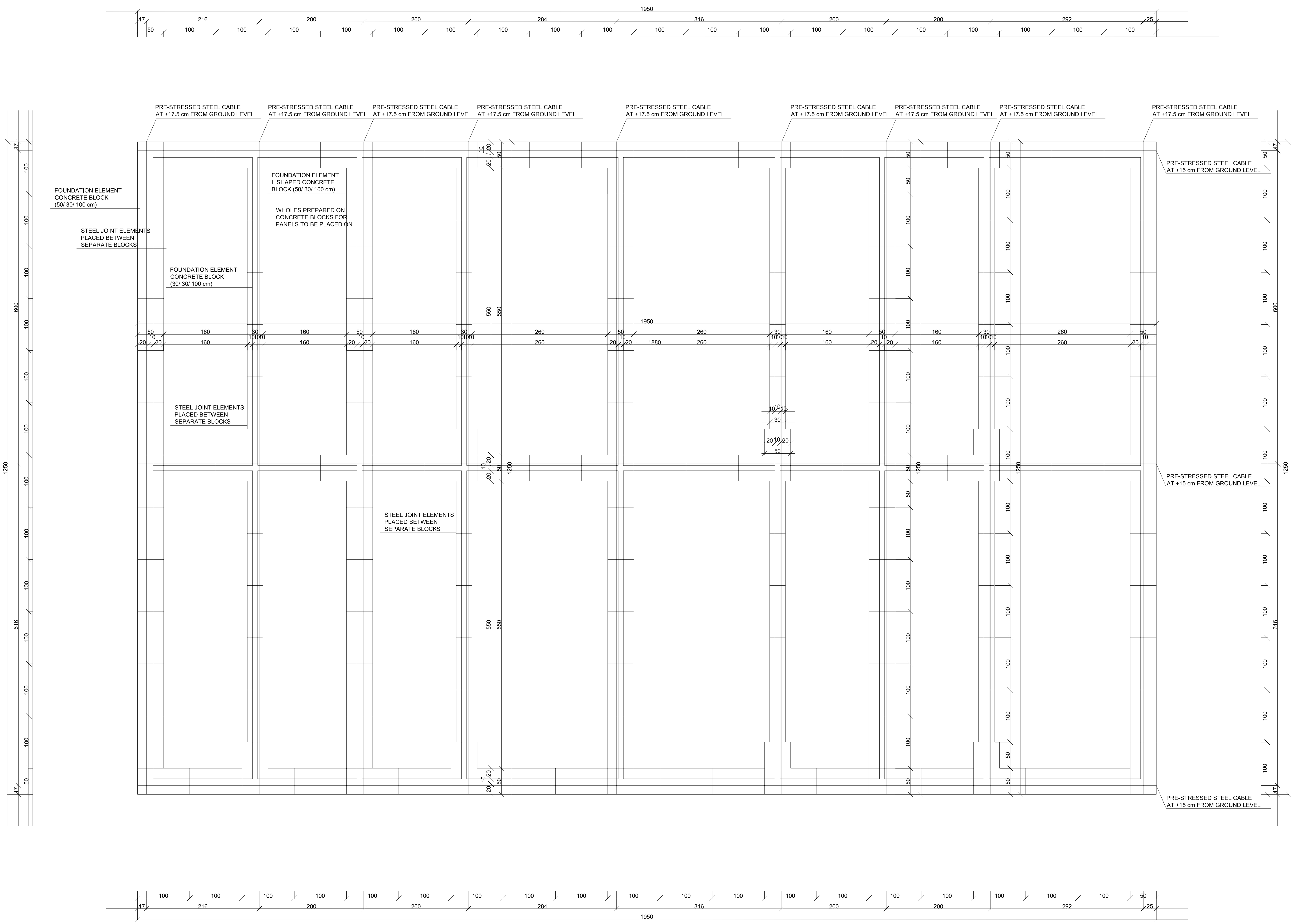
PLAN VARITIES OF THE SYSTEM



BASE PLAN OF
UNIT FOR (6-7) & FOR (8-9) PEOPLE
HOUSE FOR 30 PEOPLE

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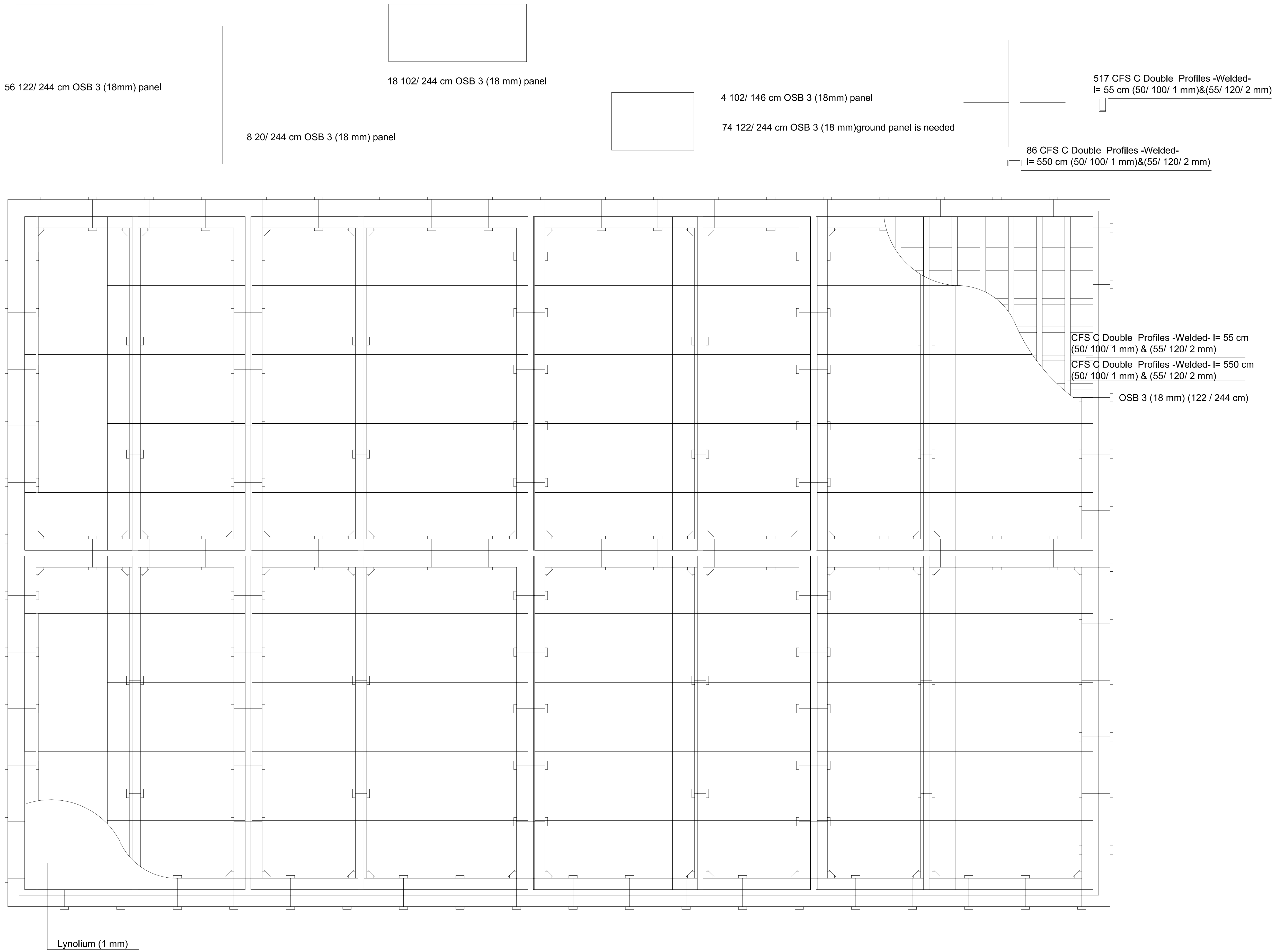

FLOOR PLAN WITH NEEDED OSB PANELS
HOUSE FOR 30 PEOPLE

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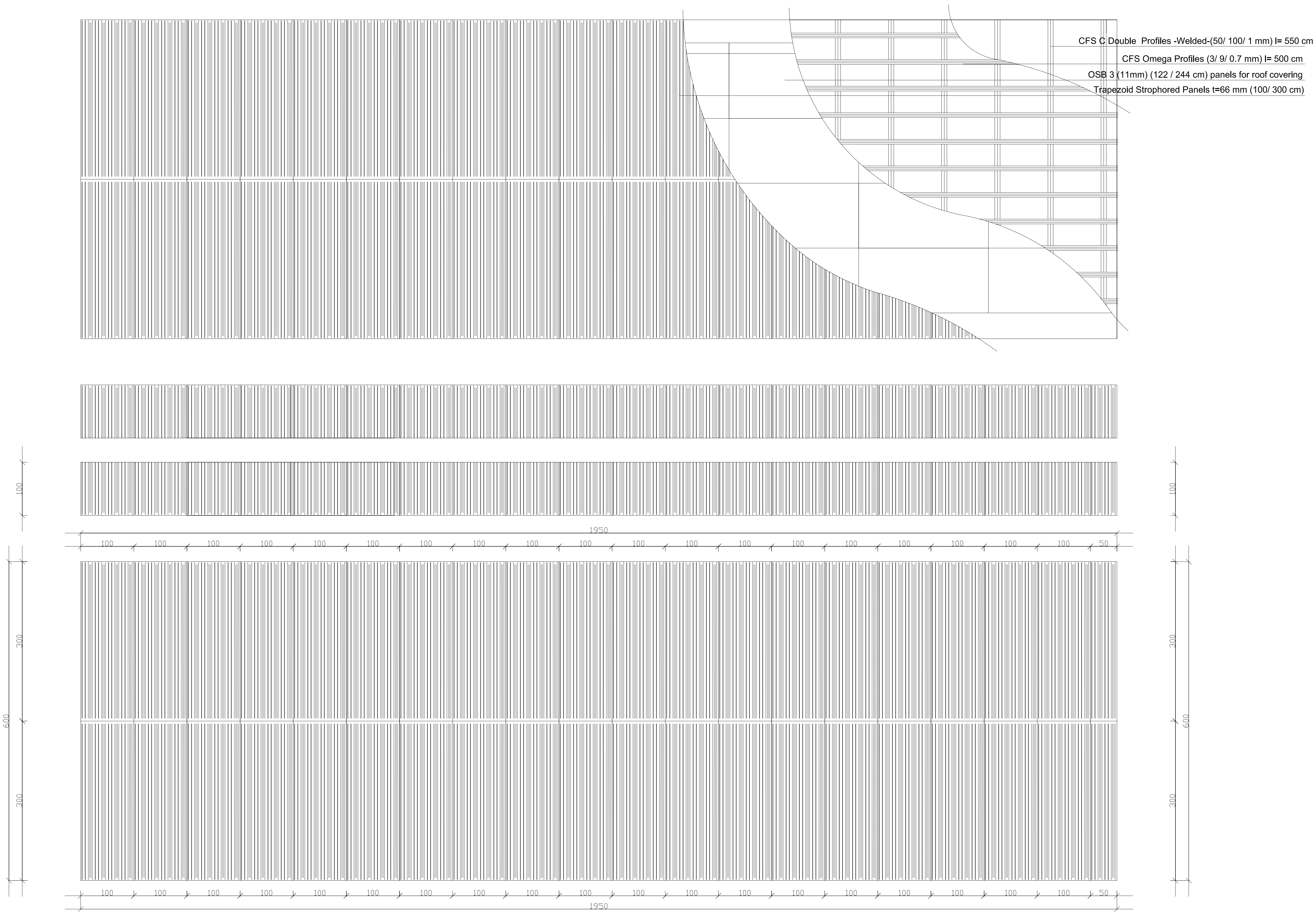

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ROOF PLAN
HOUSE FOR 30 PEOPLE

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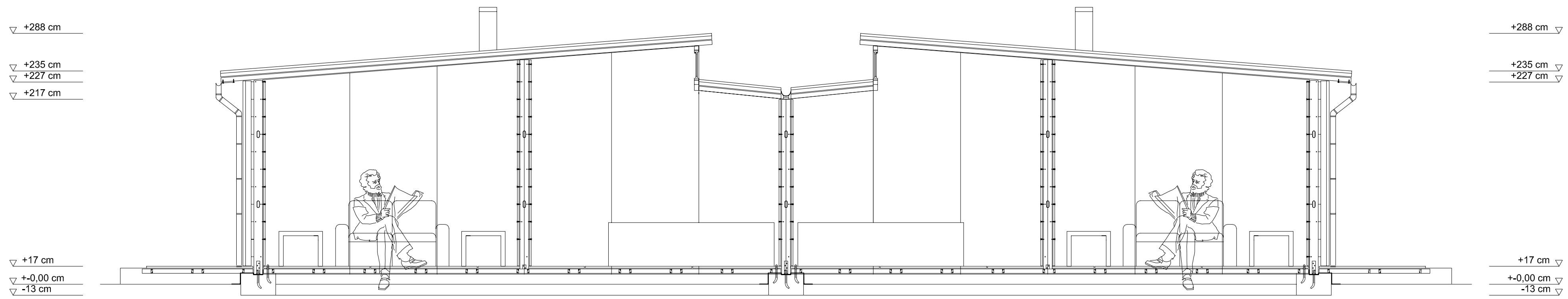
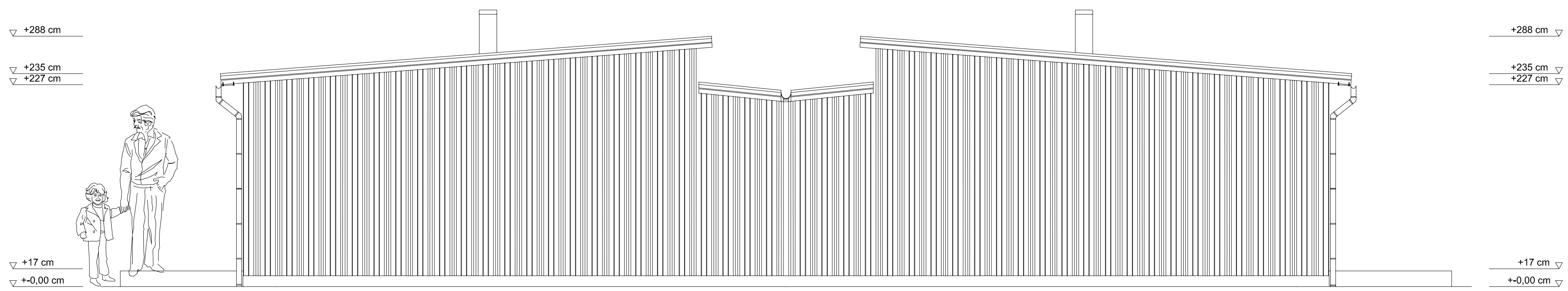
ROOF PLAN WITH OSB PANELS & ISOPANEL & PROFILE NEEDS -HOUSE FOR 30 PEOPLE-





NORTH-SOUTH SECTION &
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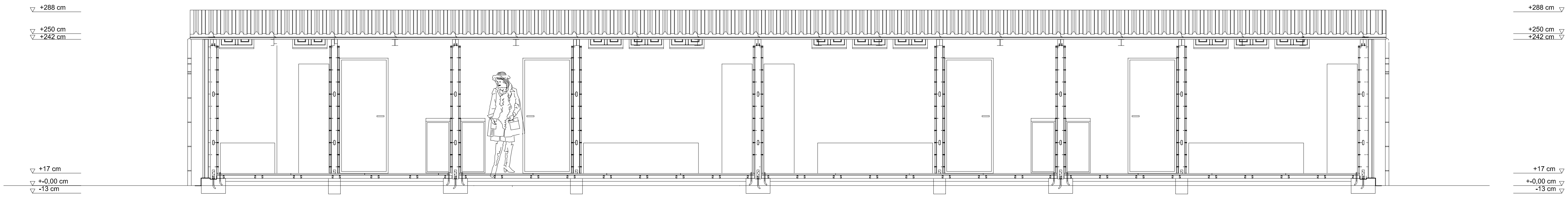

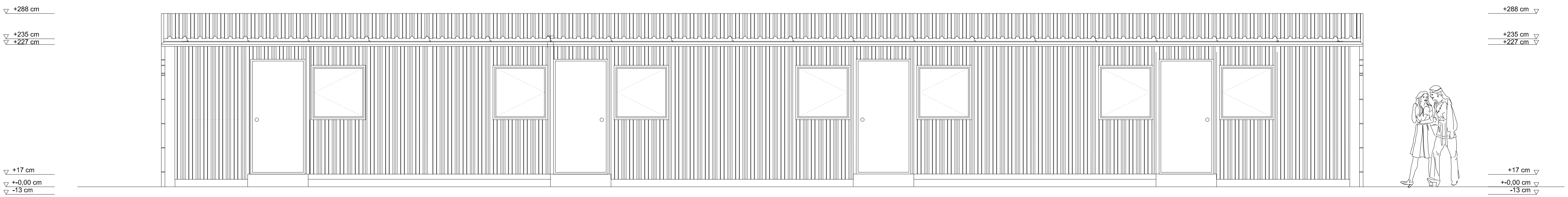

EAST-WEST SECTION &
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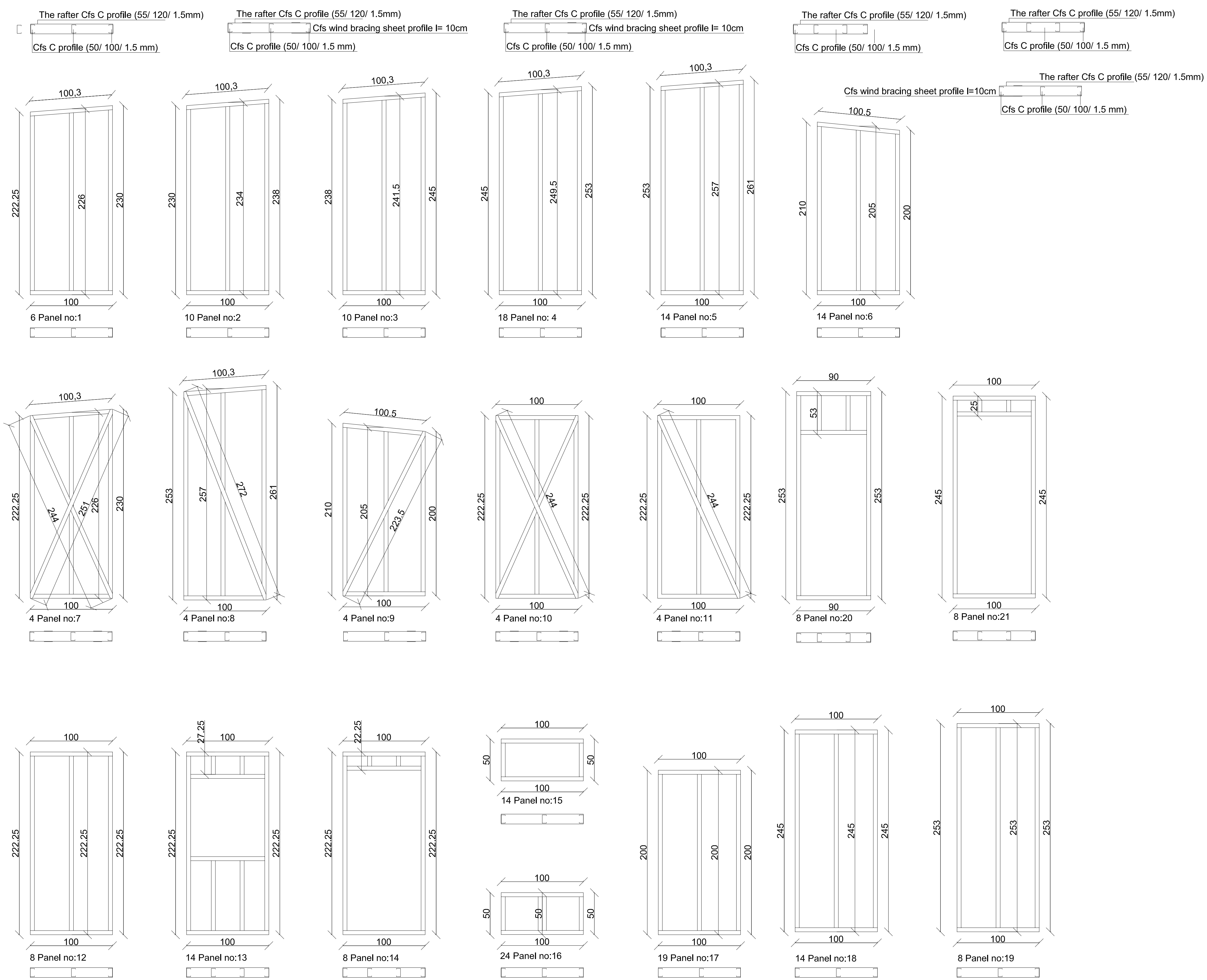
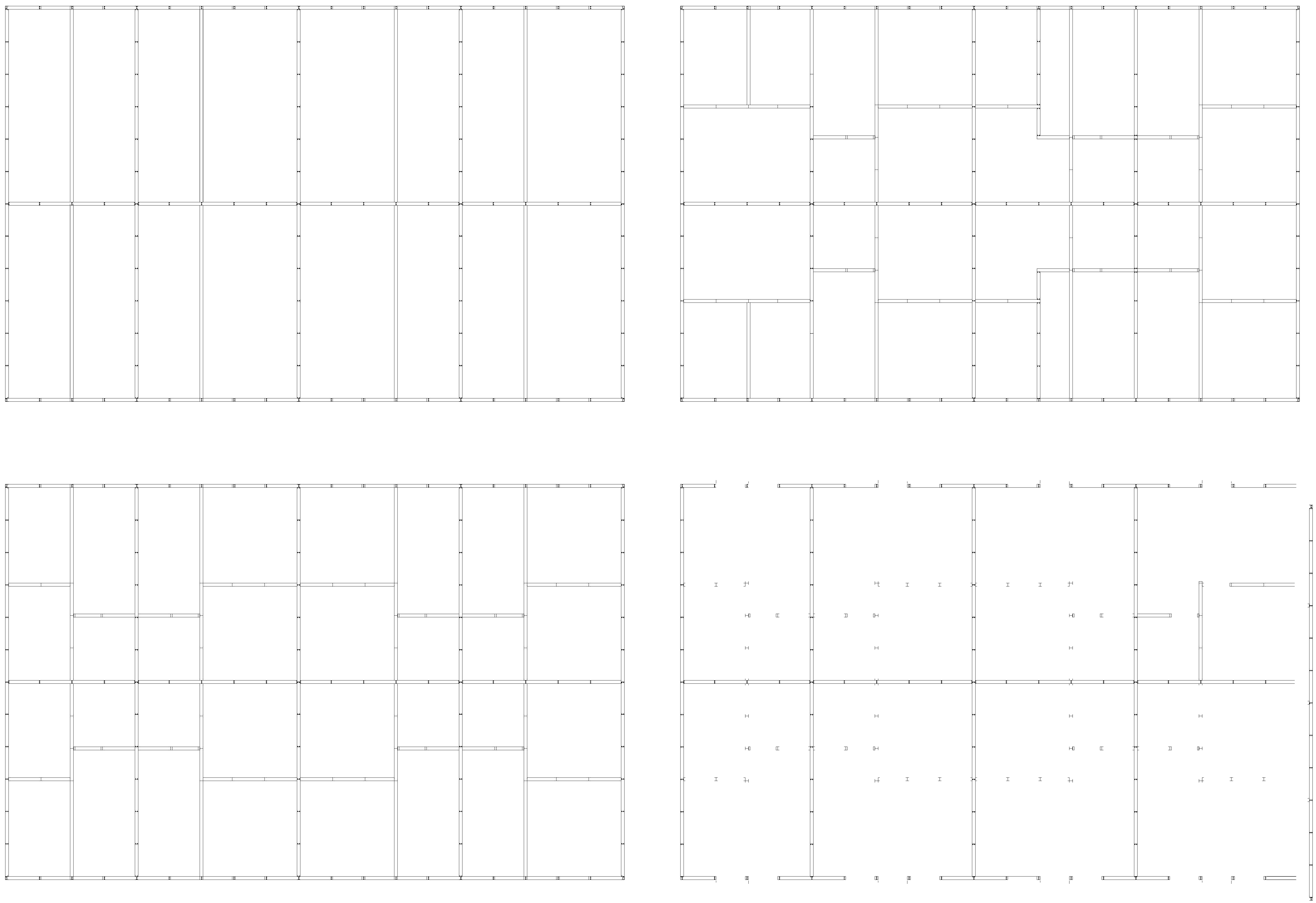
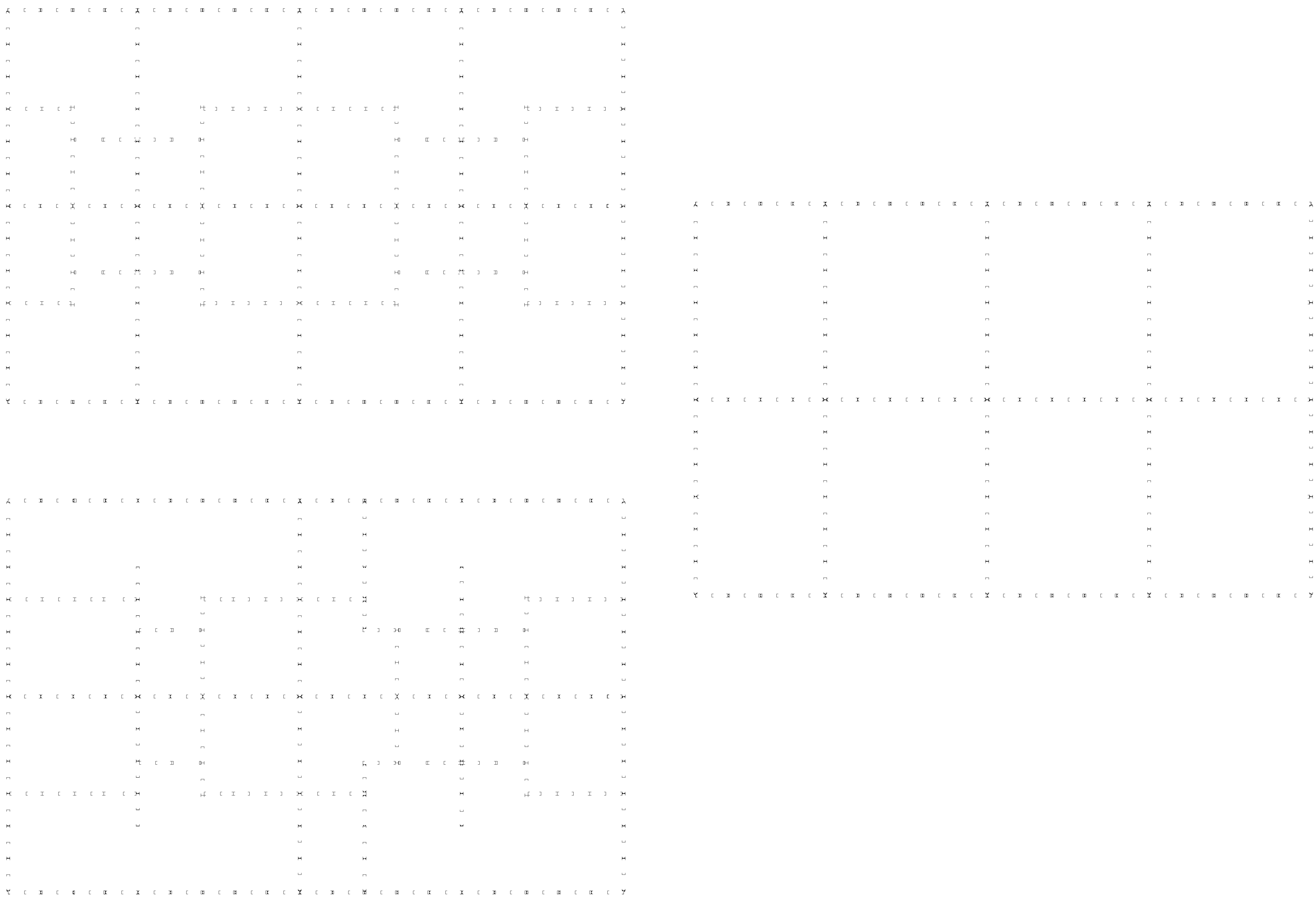


PANEL TYPES AND QUANTITIES OF LGSF
FOR (2-3) & (4-5) PEOPLE HOUSES UNIT

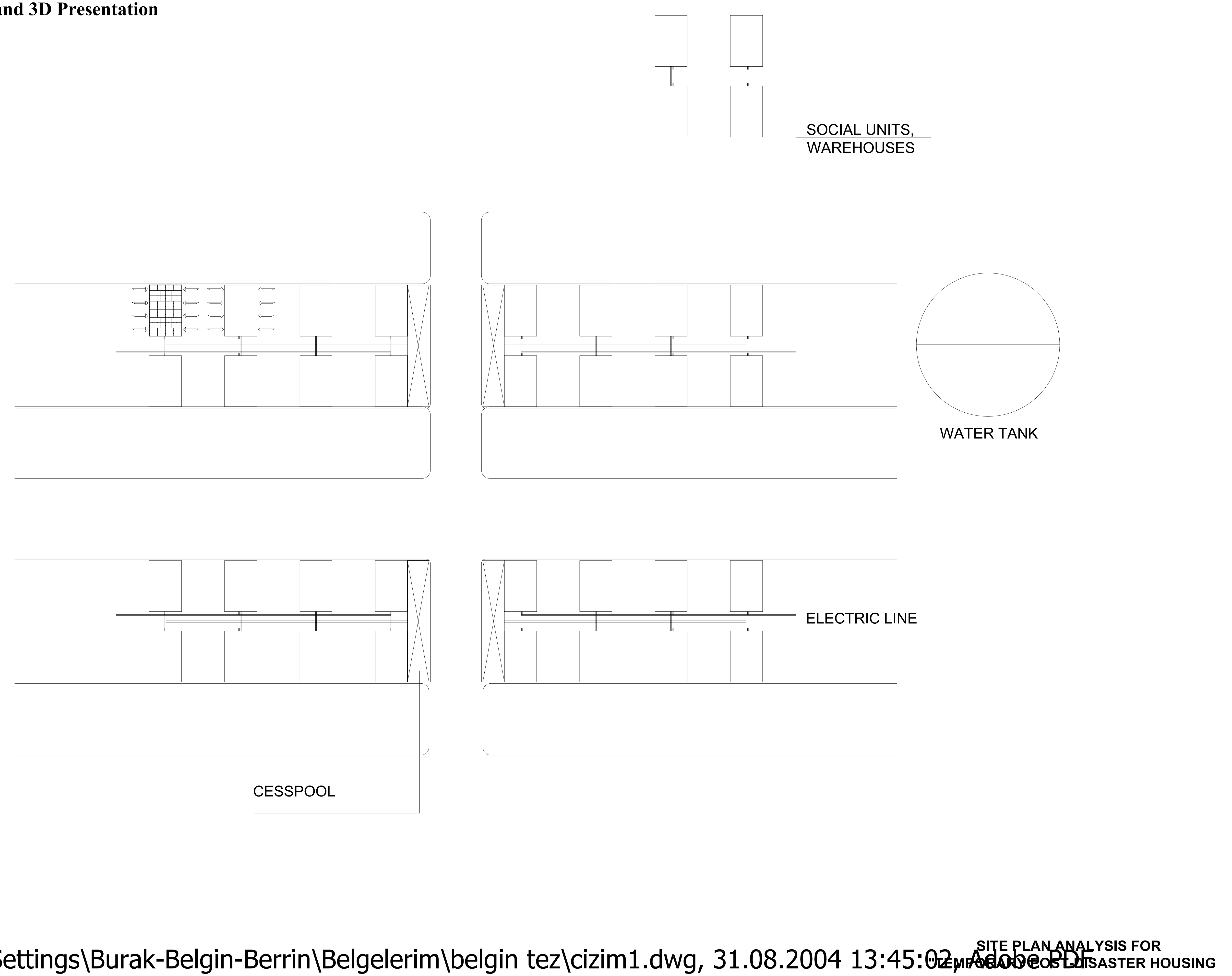


PANEL SYSTEM PLAN OF ALL UNITS (DORMITORY & HOUSE UNITS)



PROFILE SYSTEM PLAN OF ALL UNITS (DORMITORY & HOUSE UNITS)

4.3.2. Drawings and 3D Presentation



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DETAIL IN BETWEEN TWO HOUSES
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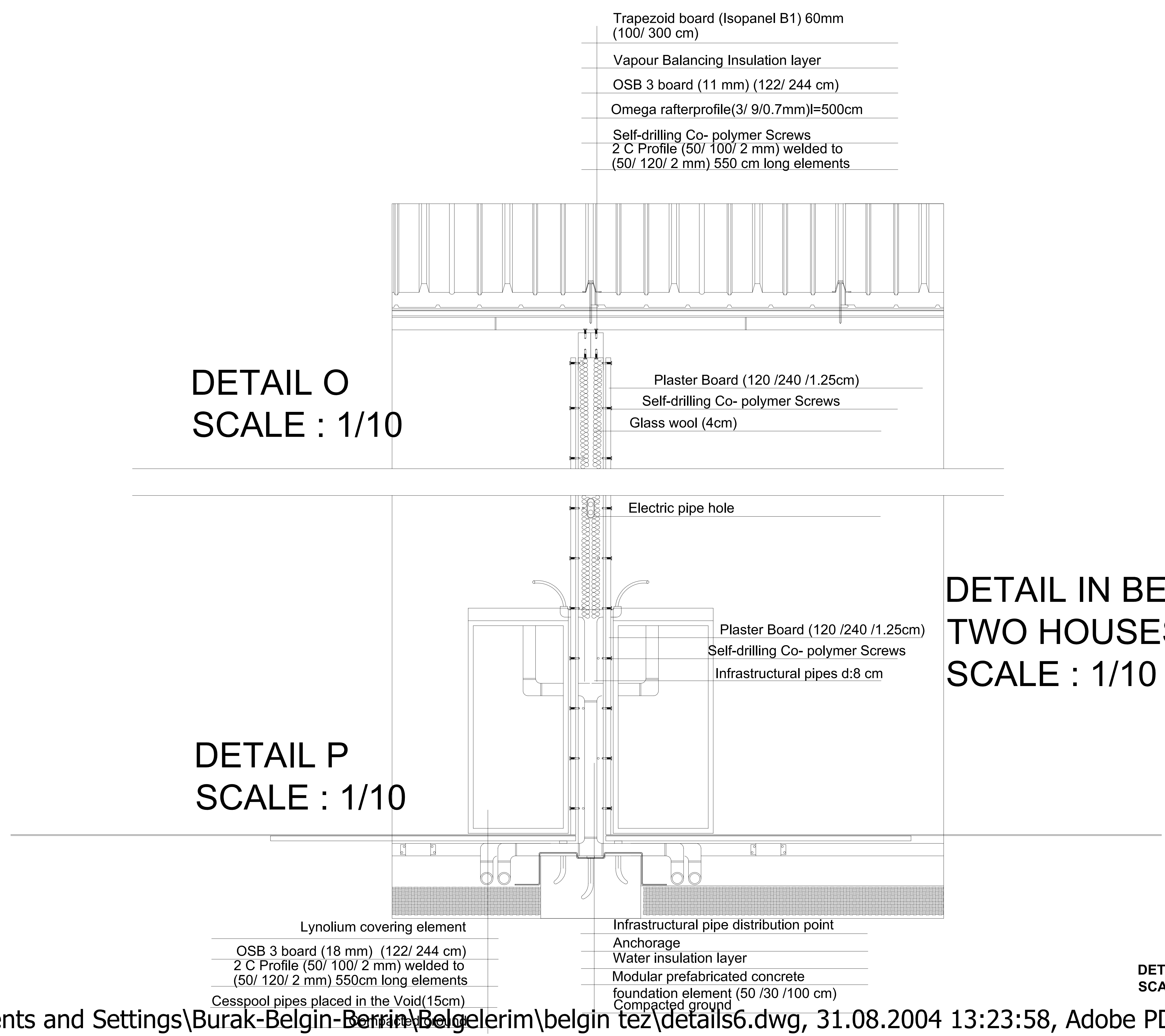

DETAIL O & P
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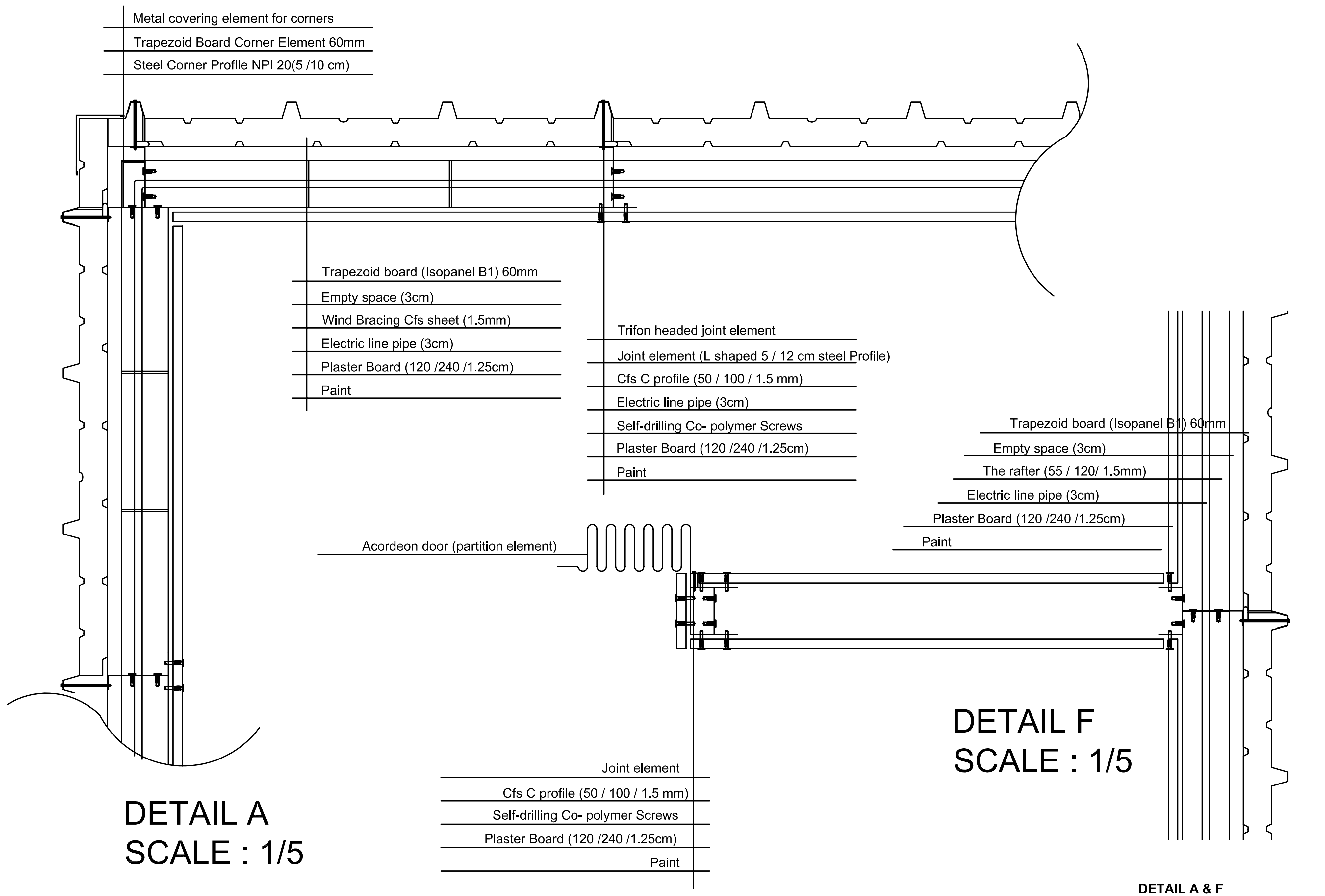

DETAIL A & F
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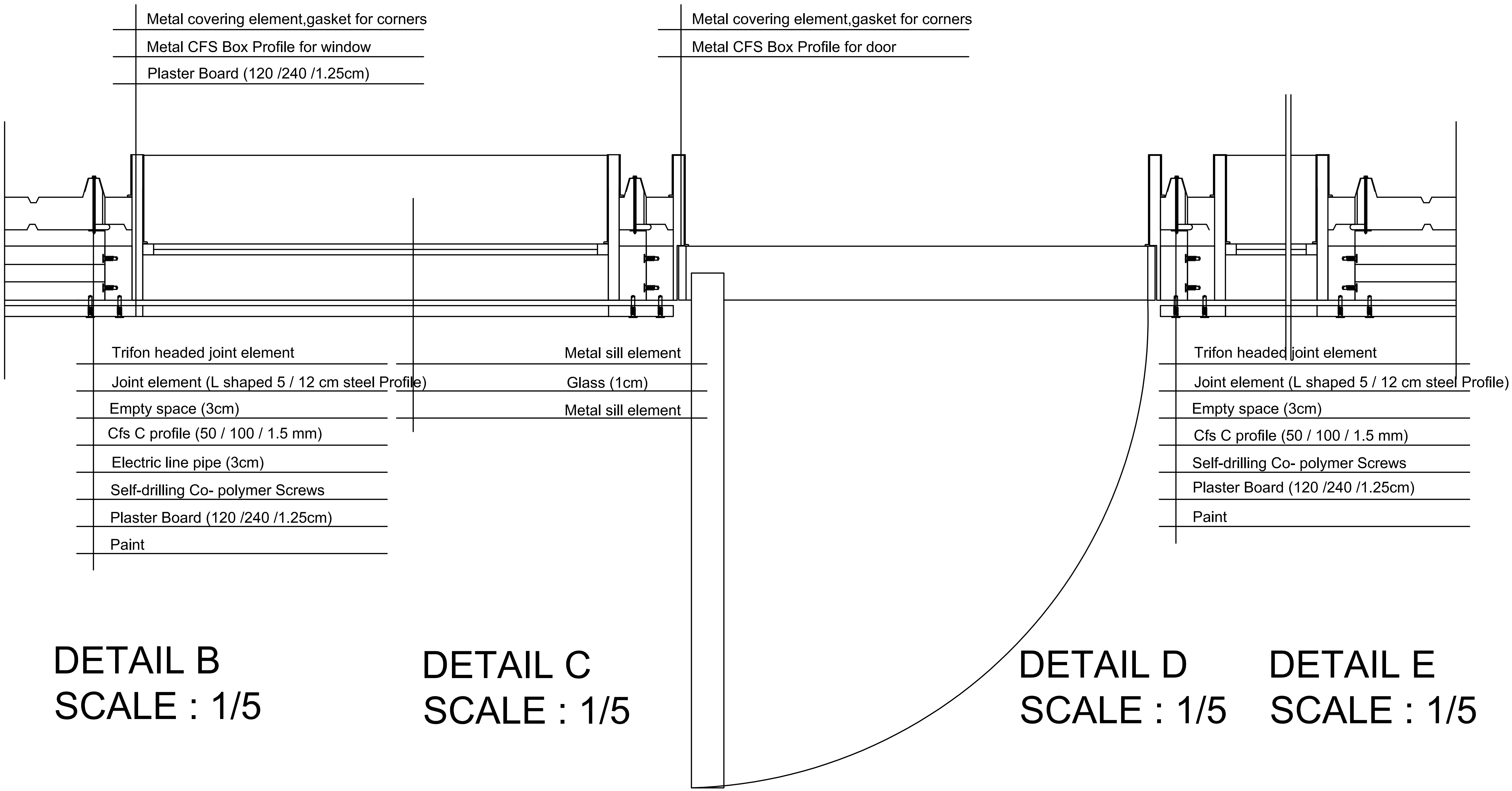

DETAIL B, C, D & E
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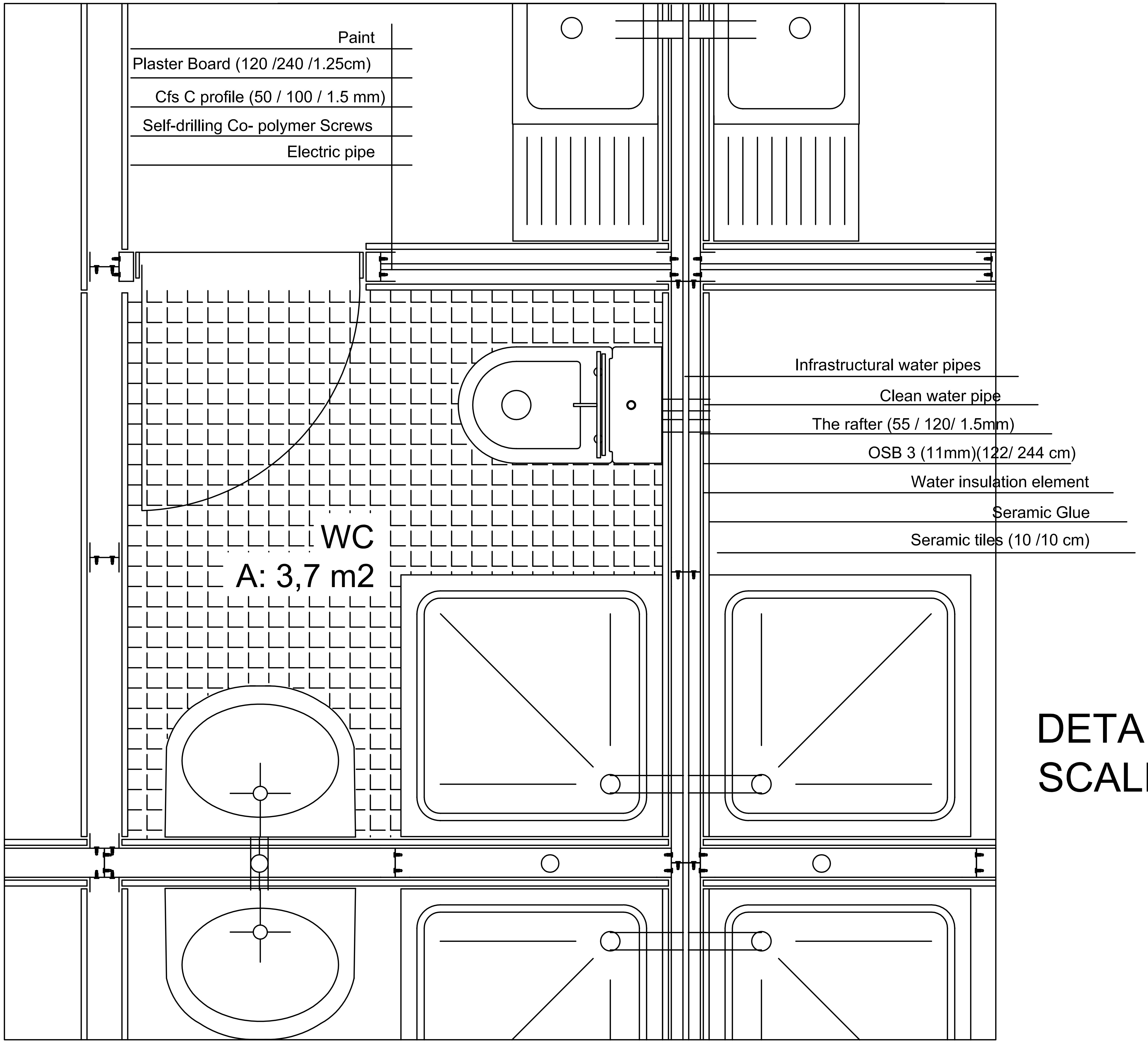

DETAIL G
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DETAIL G
SCALE: 1/10

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DETAIL H
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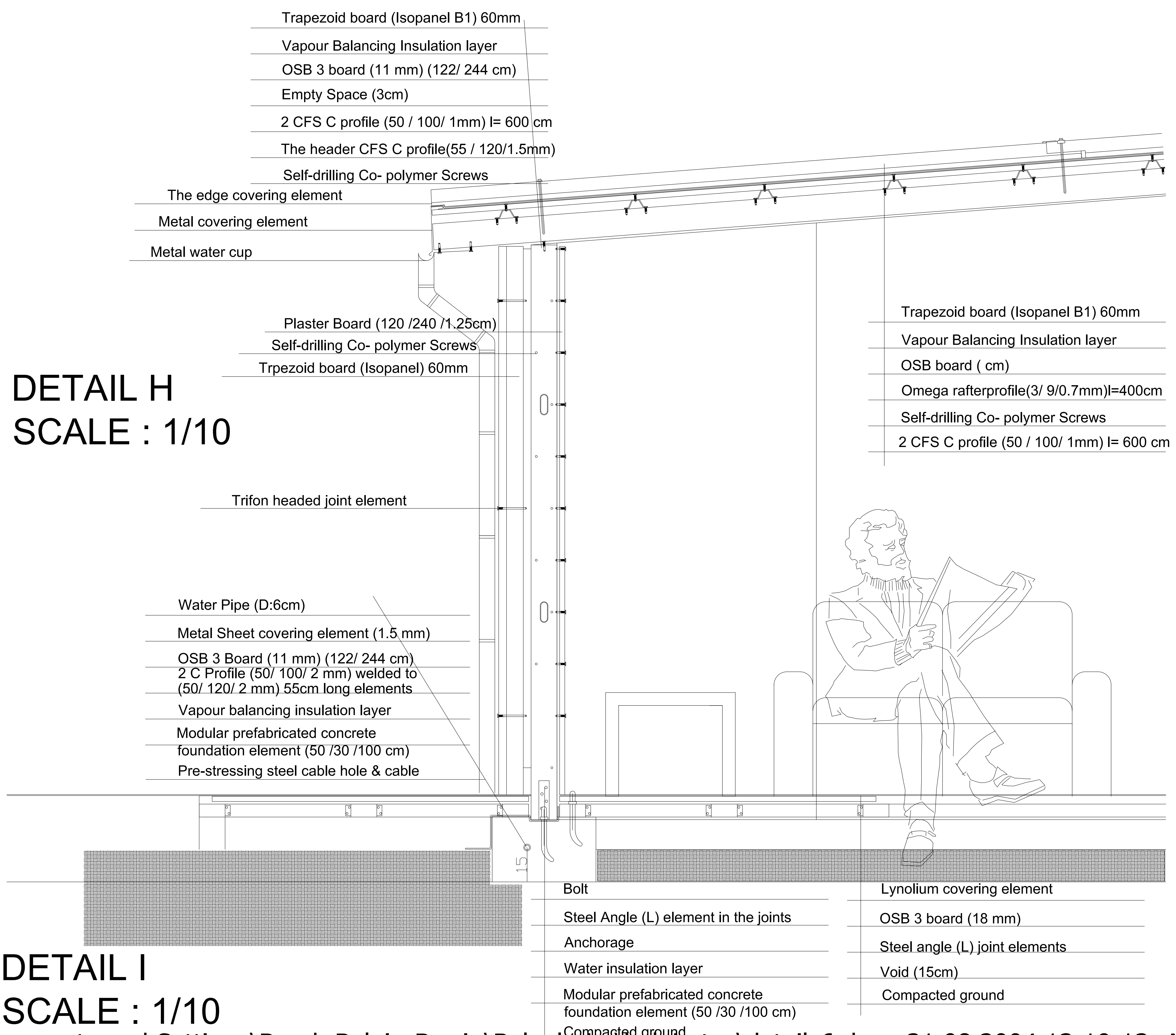

DETAIL I
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DETAIL H & I
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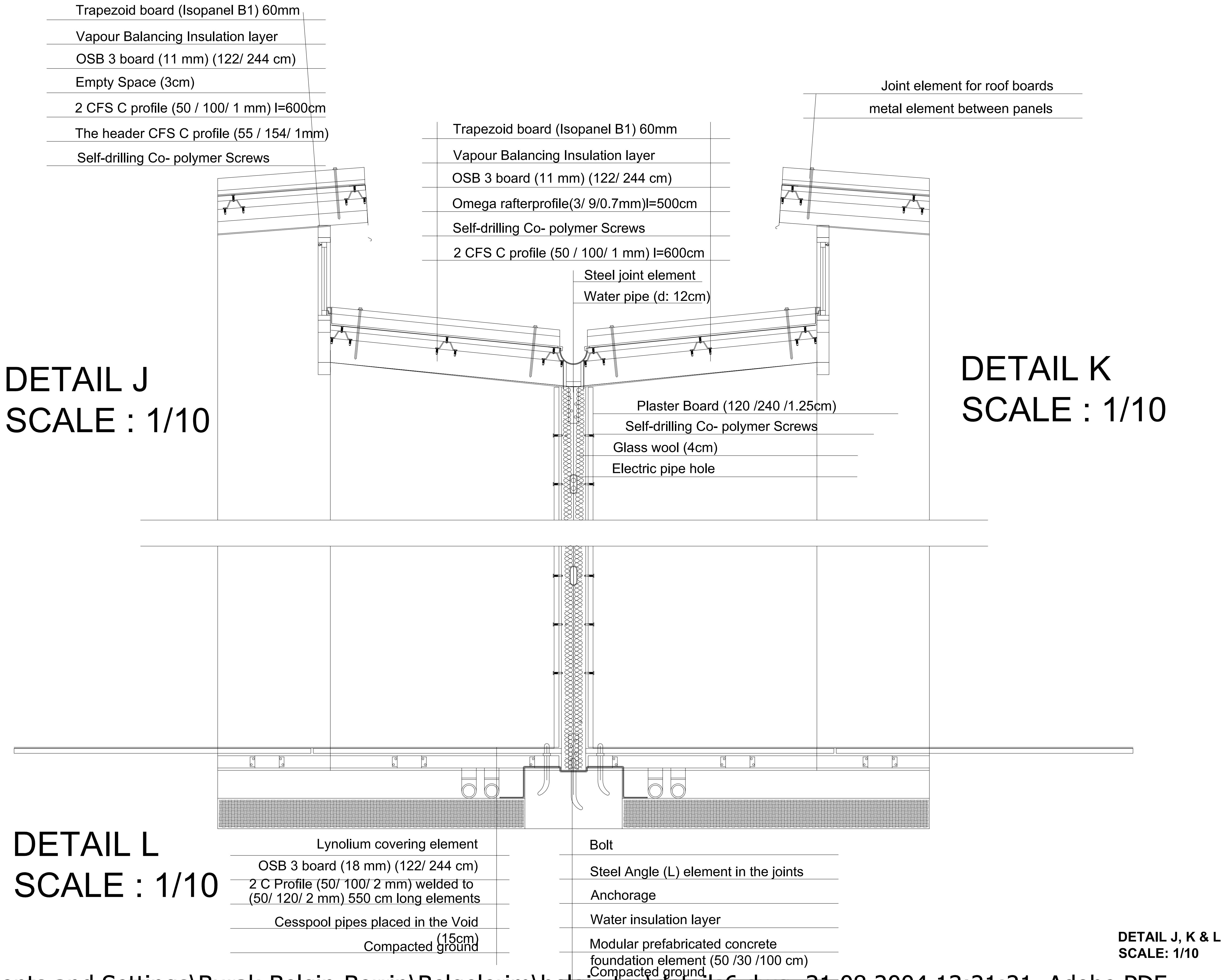

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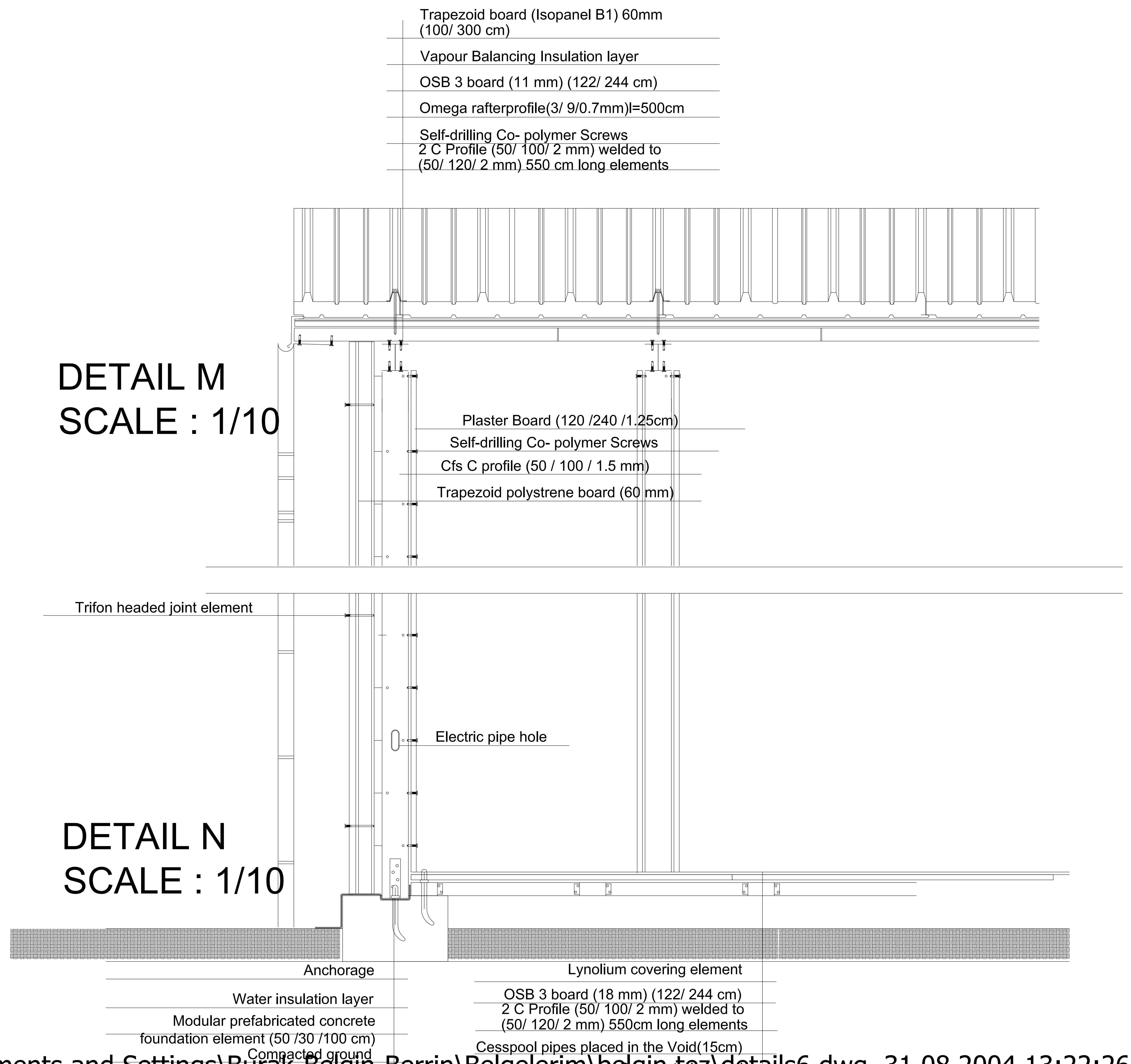

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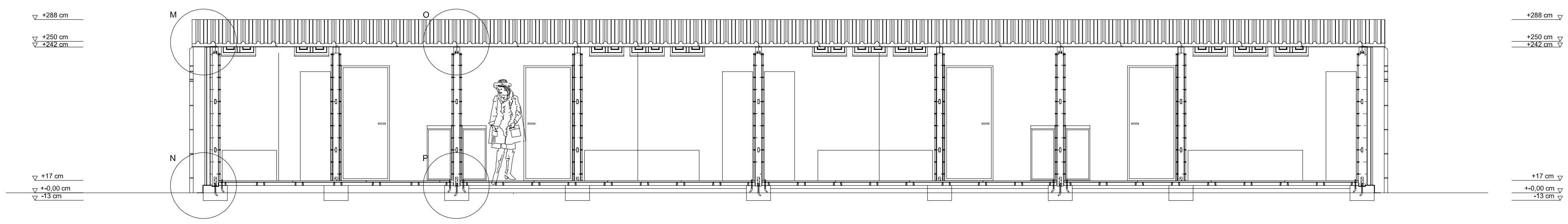

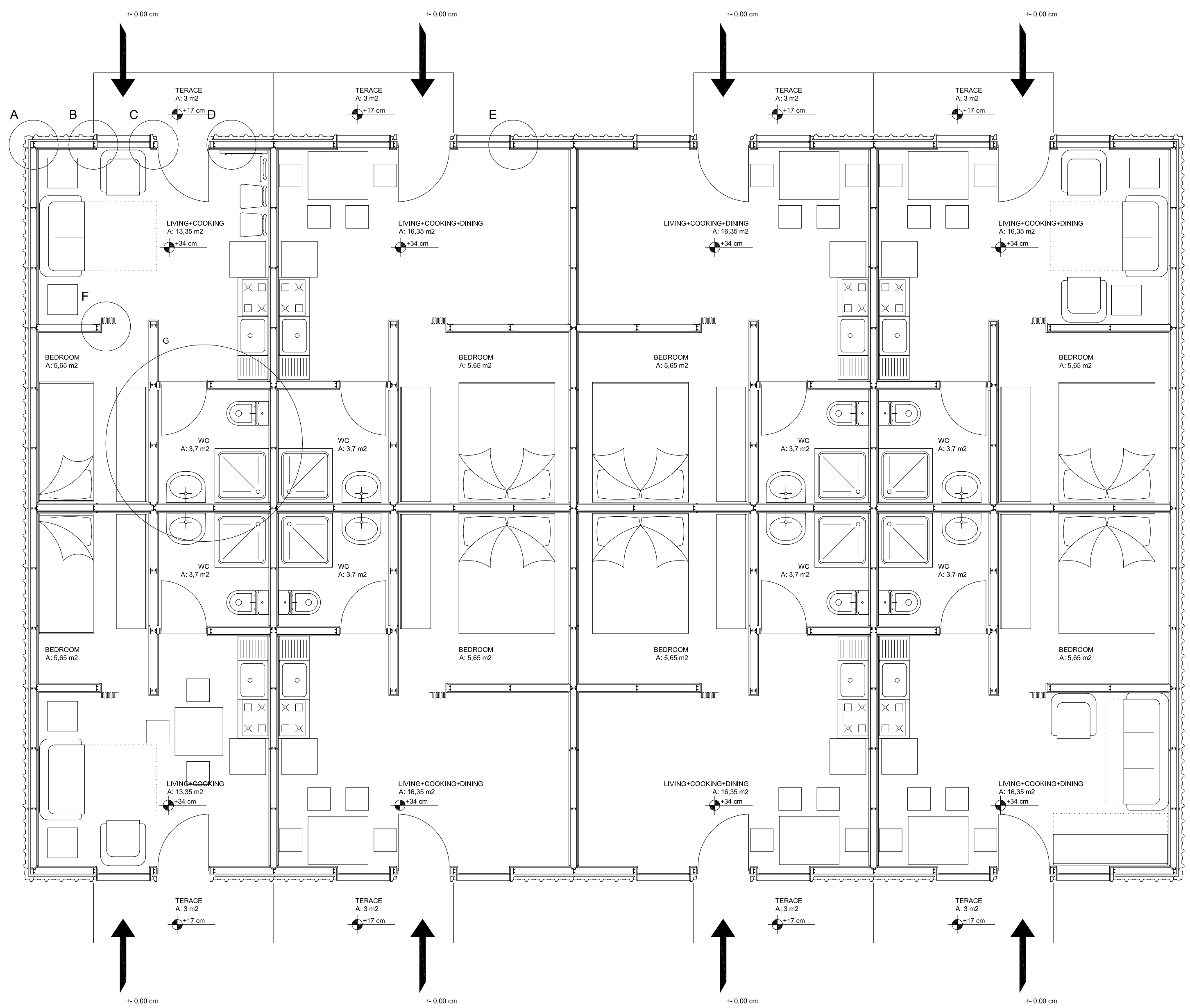

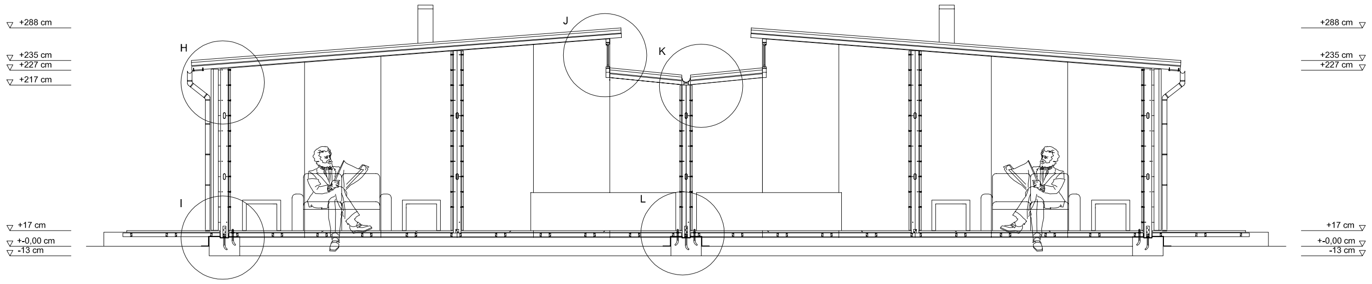

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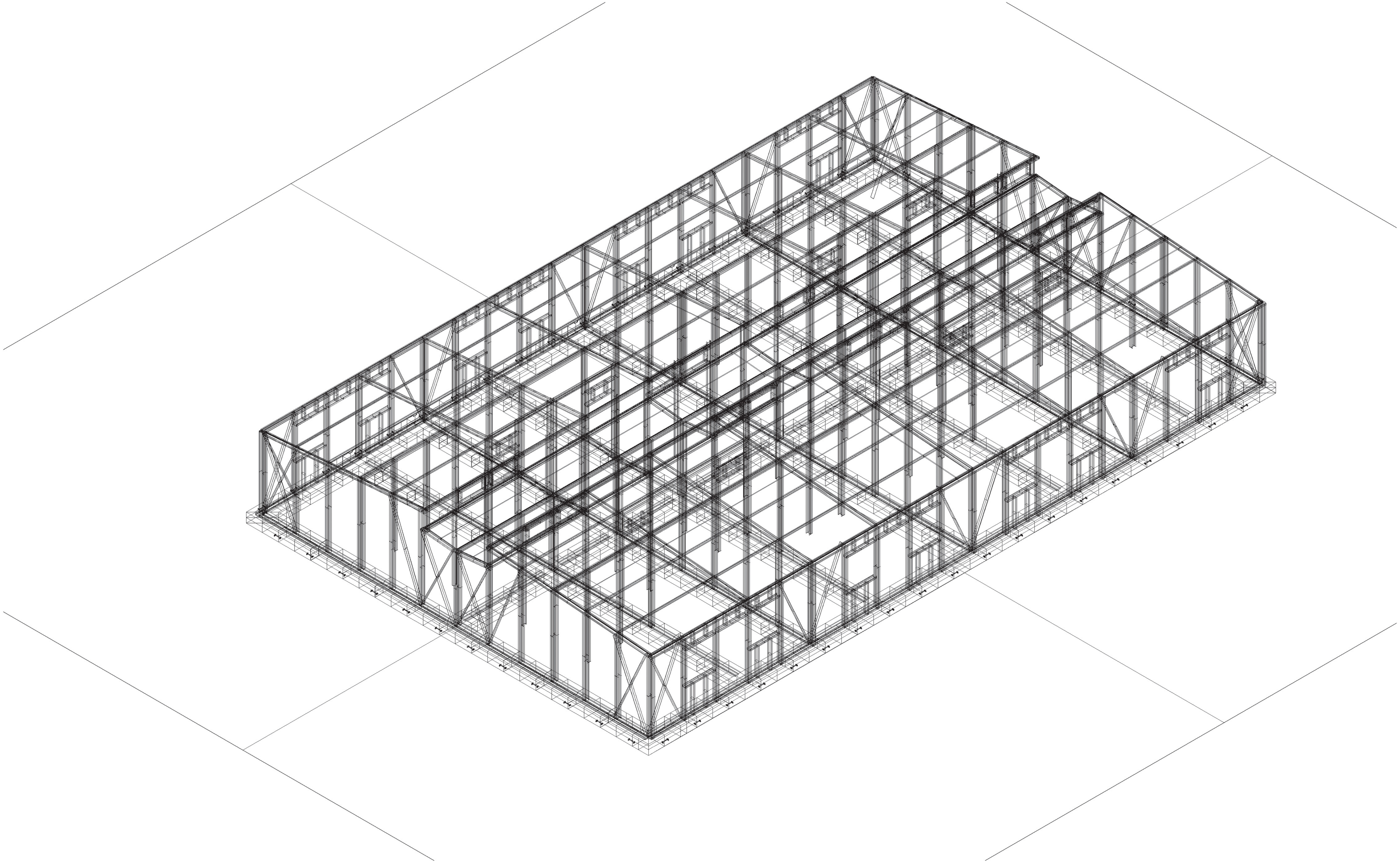
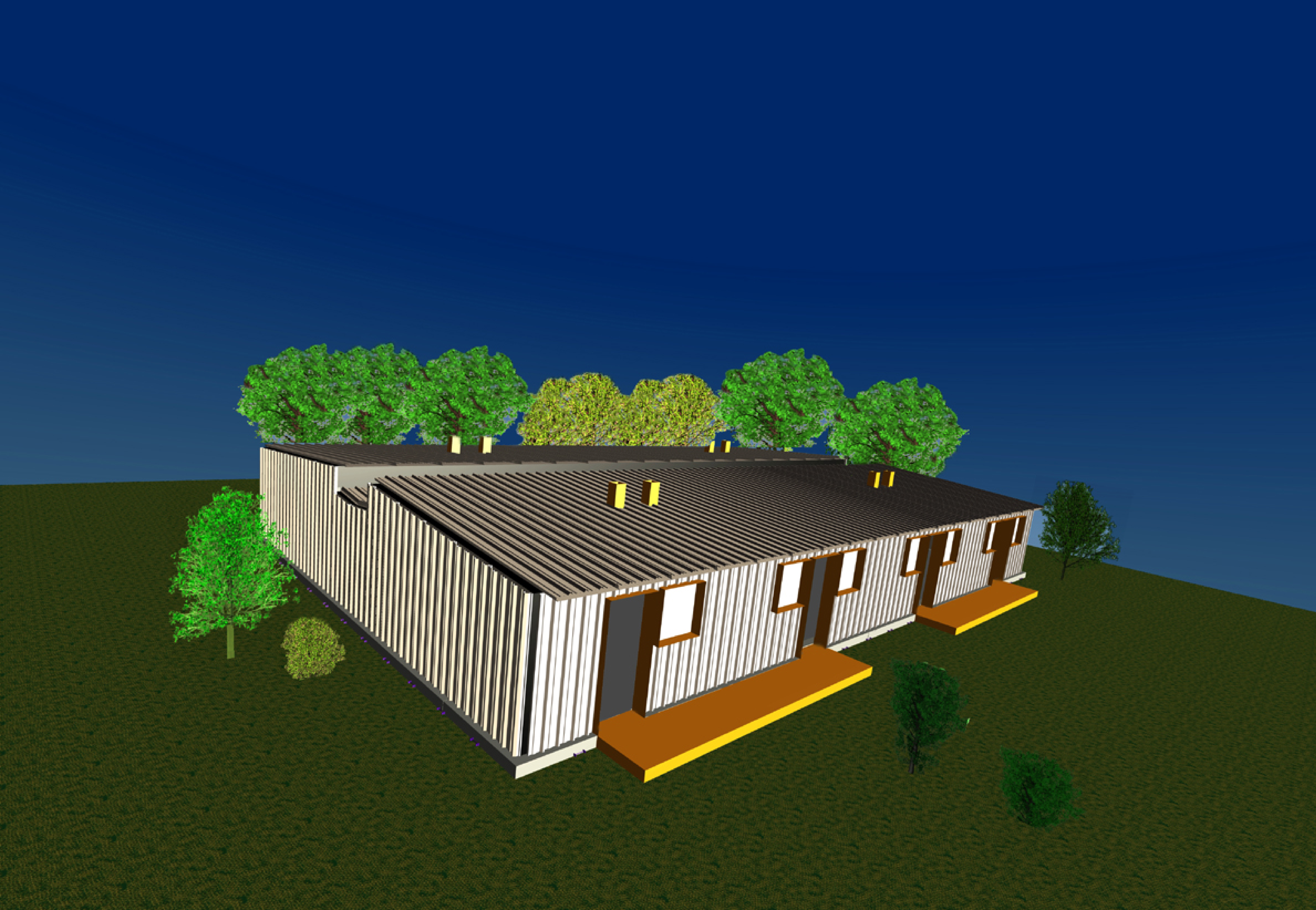
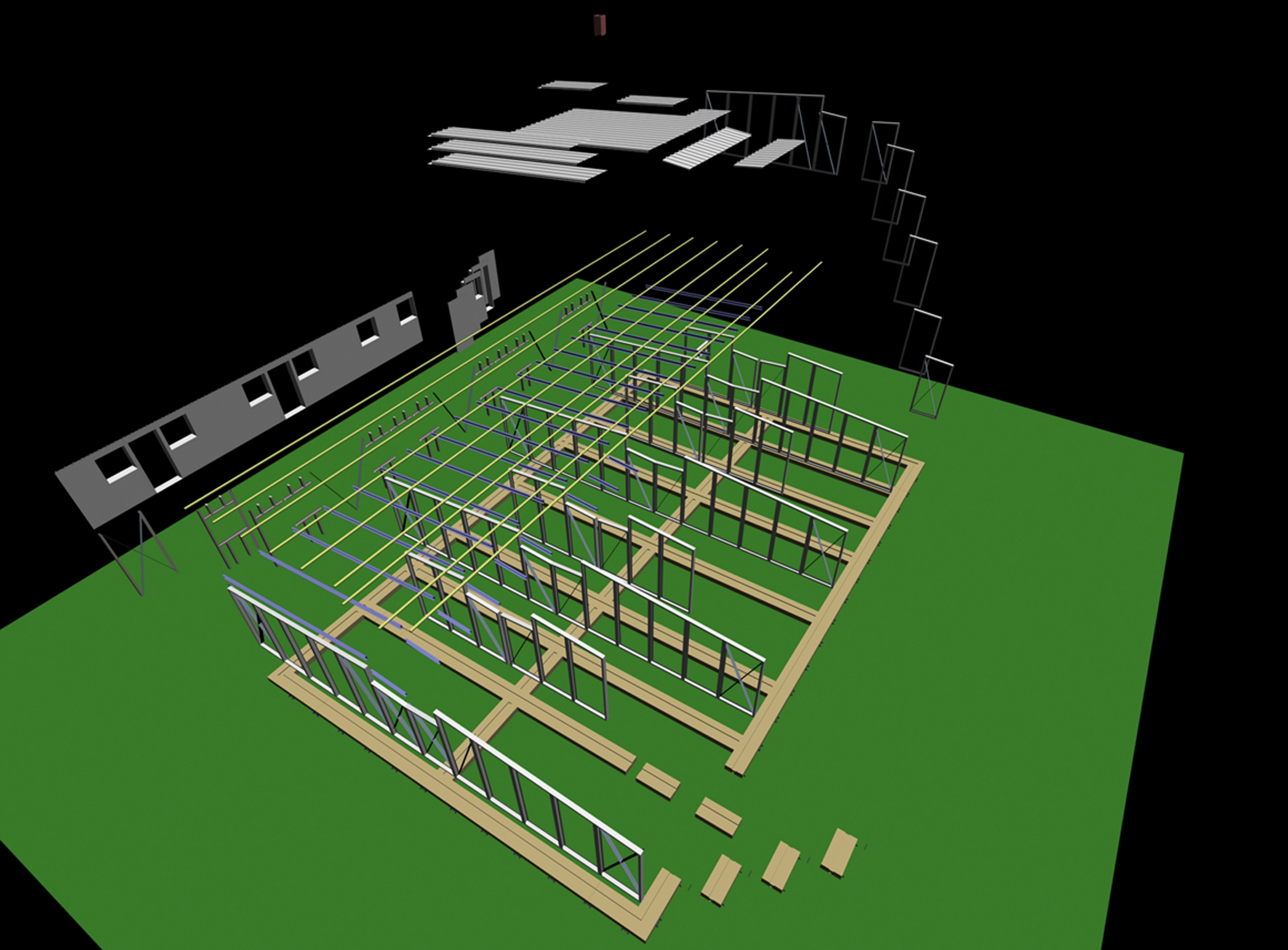
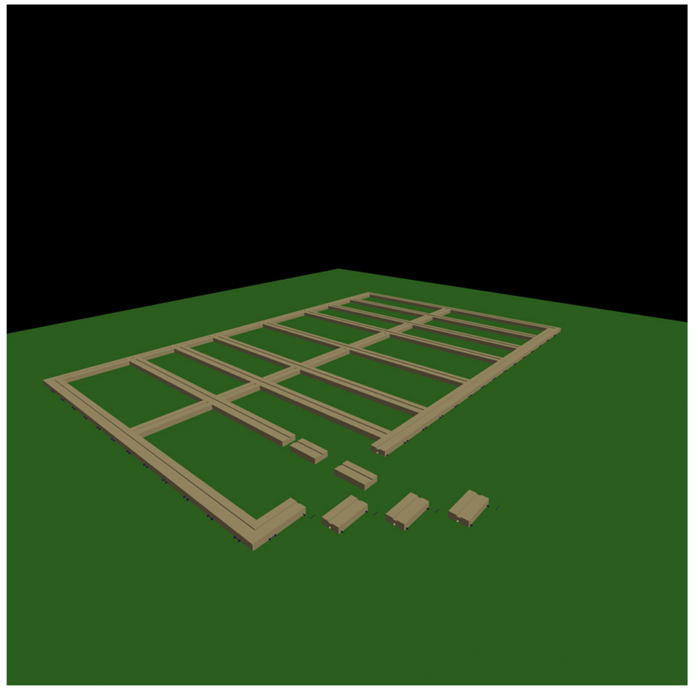
DORMITORY FOR (8) & FOR (16) PEOPLE









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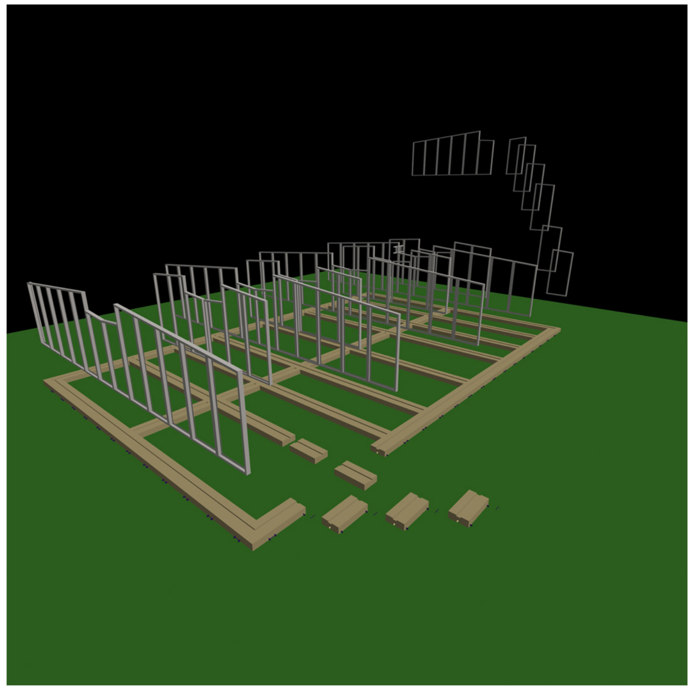

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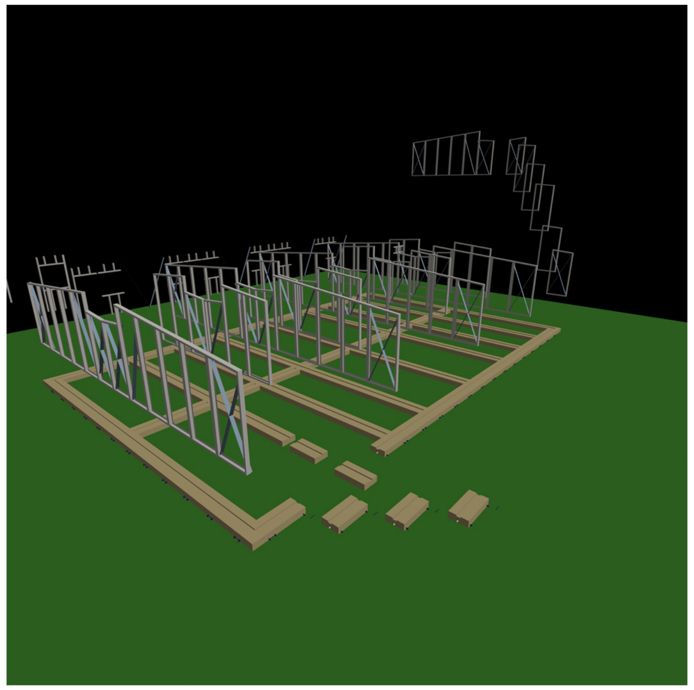

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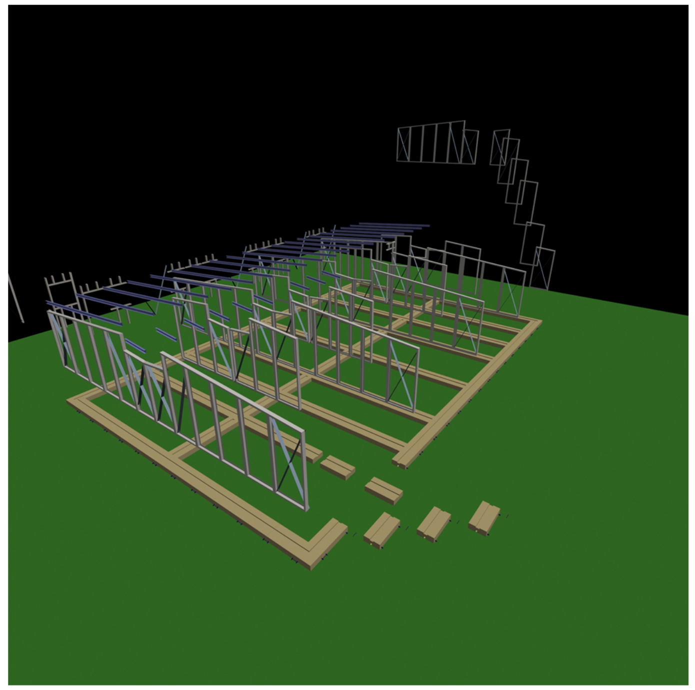

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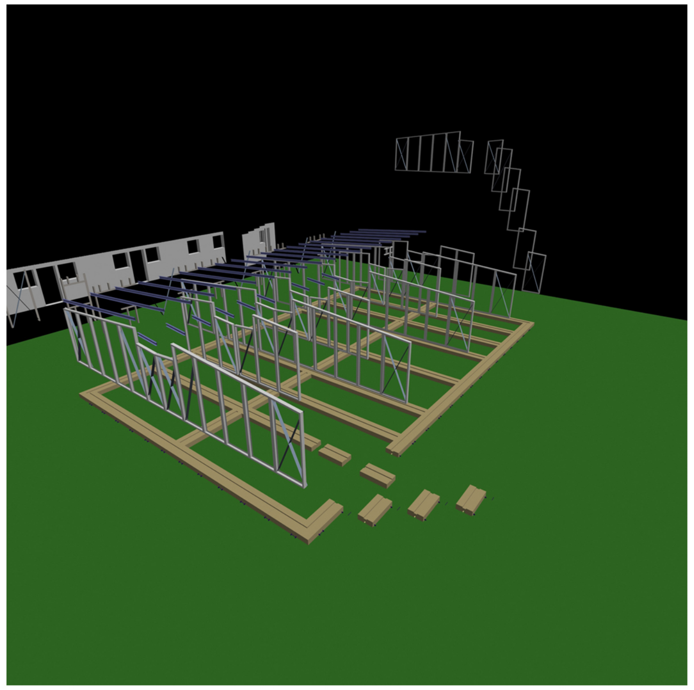

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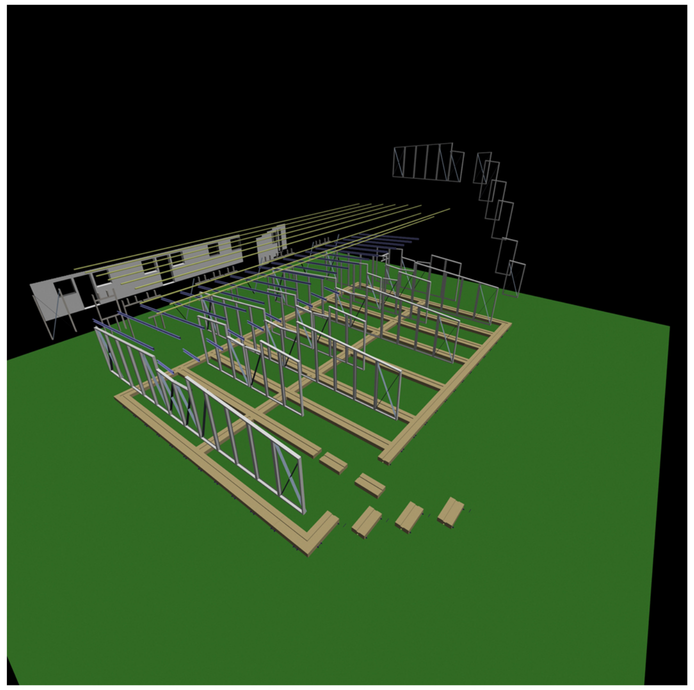

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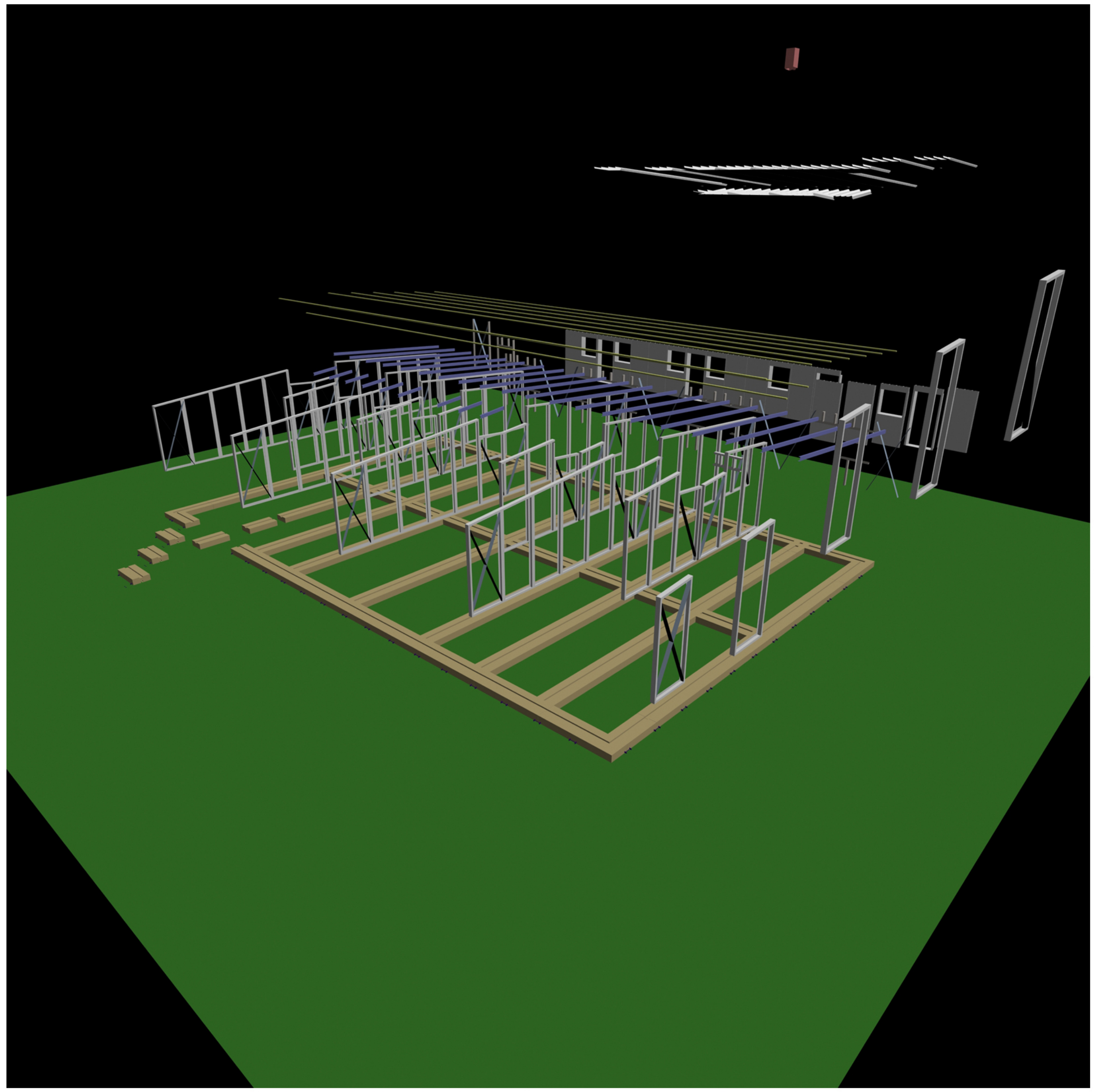
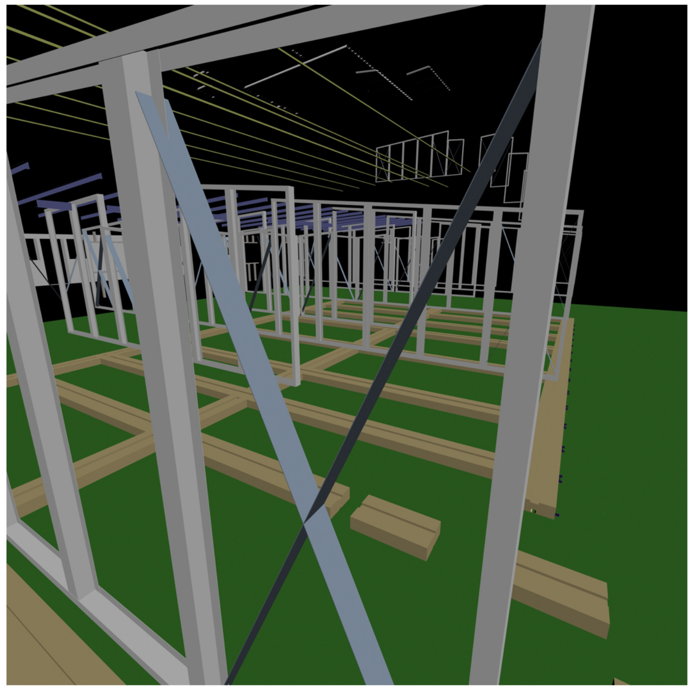
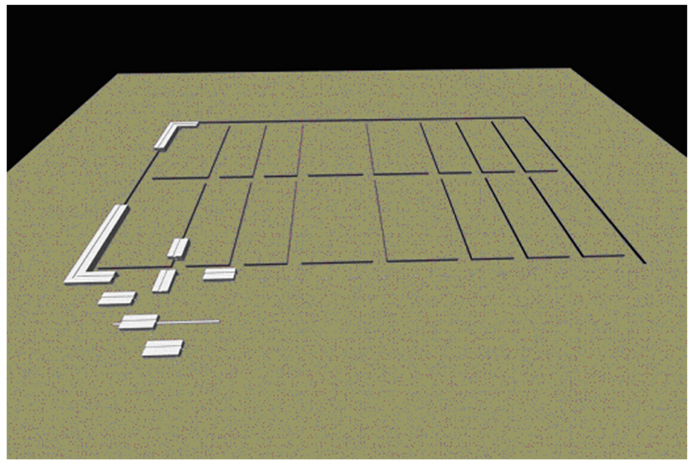
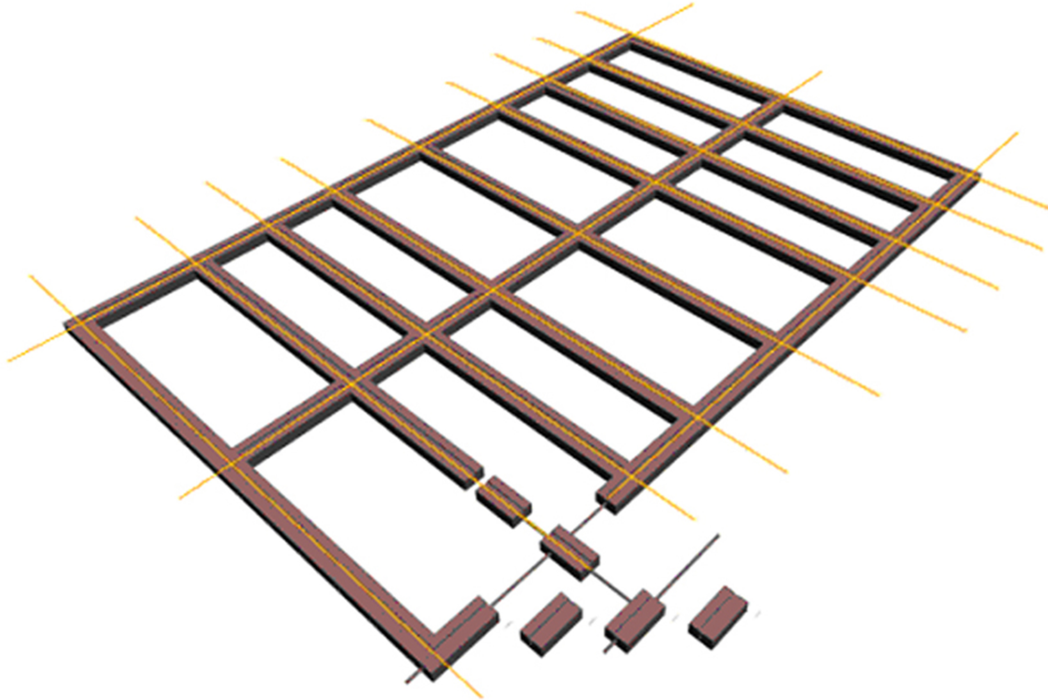
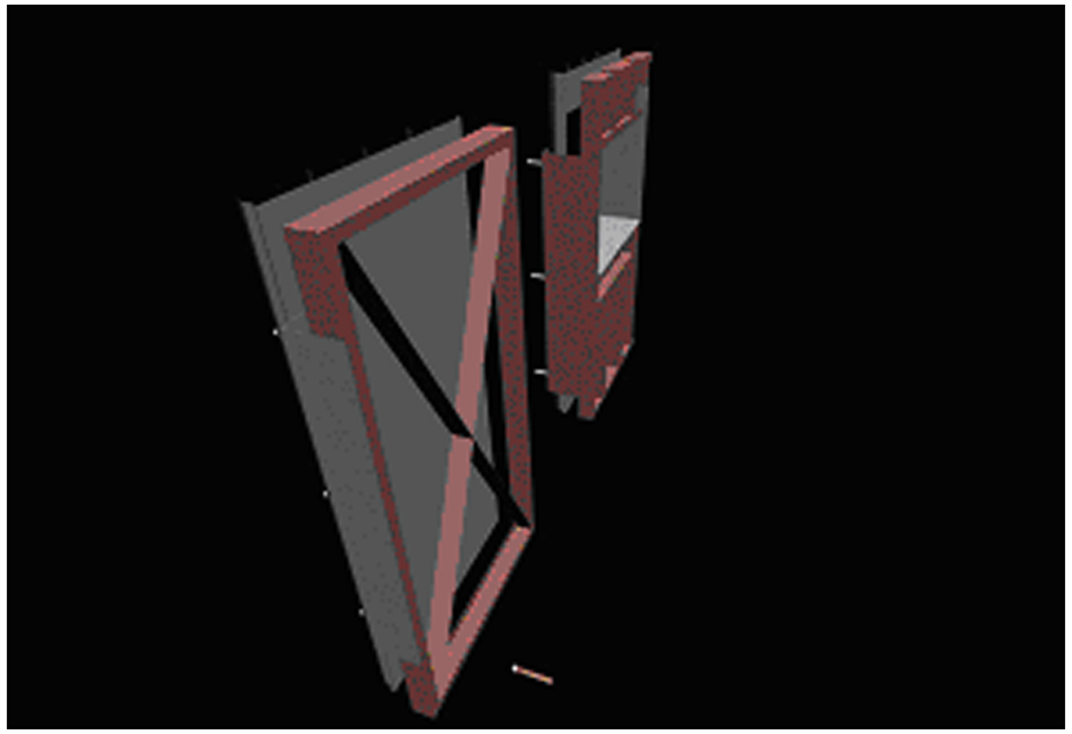
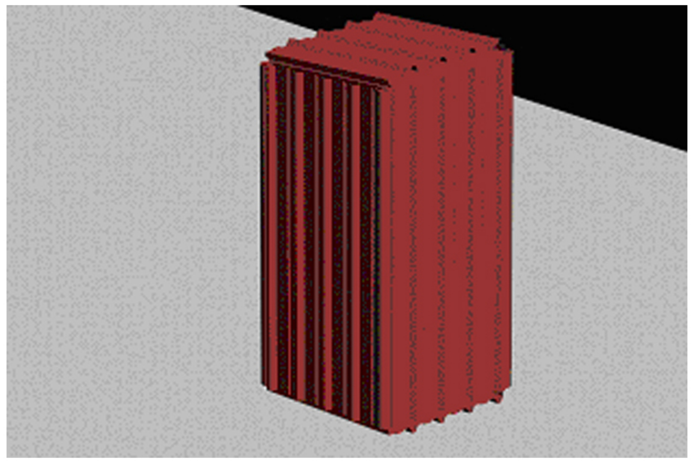
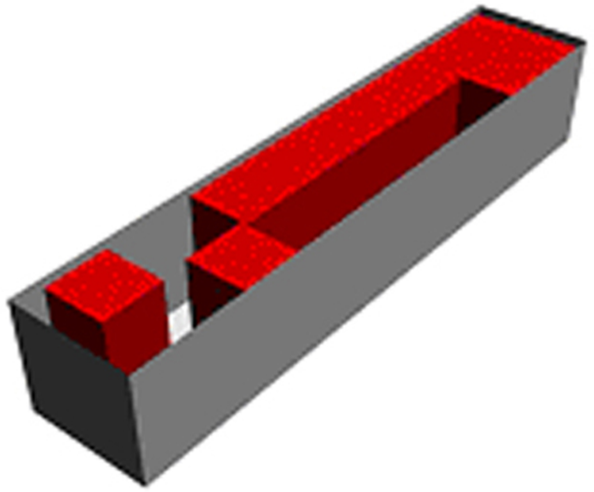


7

PERSPECTIVES OF THE STRUCTURAL SYSTEM, STEP BY STEP

VARIOUS 3D DETAILS OF THE “TEMPORARY POST DISASTER HOUSING PROJECT”

4.4. Evaluation of the Project According to Standard Optimum Requirements Defined for the "Temporary Post-Disaster Housing Unit" Design for Disaster Occasions

4.4.1. The Building-Site Requirements for "Temporary Post-Disaster Housing"

a) Evaluation according to site selection criteria:

The sites for temporary living areas are not clearly selected for Turkey. The location of the building site can be defined as the Turkey borderlines at the moment. Turkey is a country, which is mainly settled on the first earthquake zone, which has a number of floods in different seasons and faces erosion based disasters, so the temporary housing sites should be defined before the occasions happen. In the urban & regional design processes, temporary-building sites should be pre-defined in accordance with the requirements in section 4.2.1 in this study and in other more specified studies (references) on temporary living site planning.

In this project proposal, the site plan is only a simple analysis of the roads in the site with the location defined for the infrastructure elements. (look Drawing 5.1) The housing blocks should be located perpendicular to the main roads in order to hide the infrastructure elements going in between the two lines of house groups. The short road perpendicularly bisecting the main road will be used as the service road where the cesspools can be emptied. The main characteristics of the proposed site plan can be taken as the first directing data, in the use of any defined site, but it is possible to make better site variations. If the temporary sites would be pre-designed in the urban context, the variations can be made in these sites according to the different site conditions. The sites must contain the social and infrastructural facilities nearby.

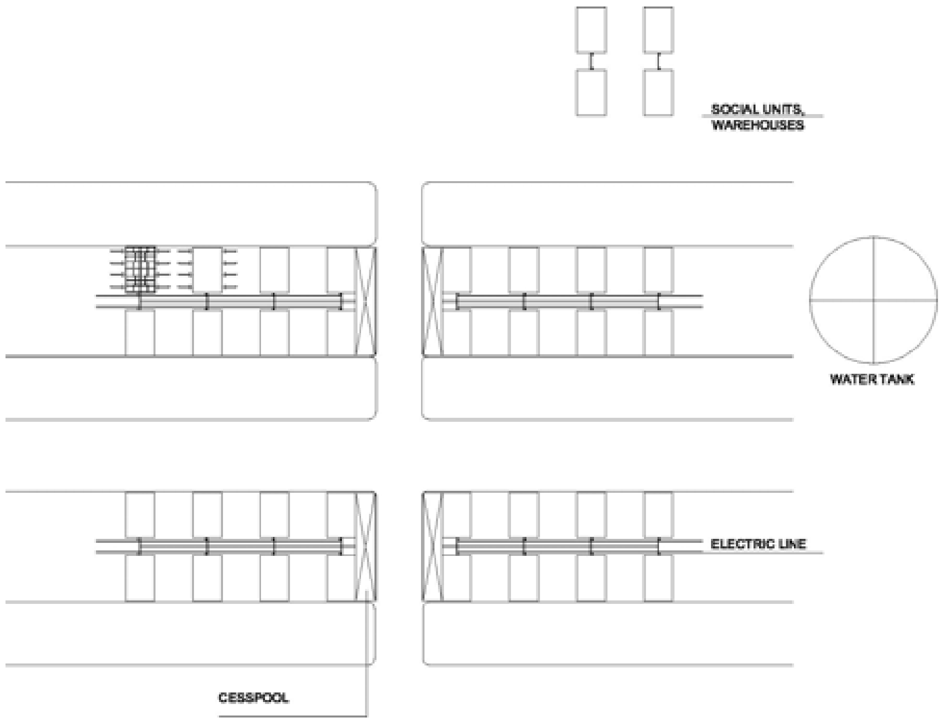


Figure 4.1 Site Plan

b) The Characteristics that should be concerned while planning in the site:

In this project, the general area is suggested to be around 43.000 m² for 1000 people that will live in the site, which is 43 m², suggested for each person with the transportation, infrastructural and service facilities. In each group of housing 32-64 housing units exist and the units can be enlarged to the areas at the back. It's suitable to the site requirements of Abeles, Schwartz & Associates which is shortly defined in section 4.2.1. Every house can own a green area in front of their main door in the system.

The commune area at this site has extra importance for the psychological and social status of the people as Eyüce said. This new proposal offers the first 8 housing units (dormitory units) brought to the site to be converted for the public functions and storage areas after the montage of the main temporary units has been finished. Facilities like laundry, shopping area, health clinic, school, communication center, temporary kitchen, meeting halls can be adapted in these units after the construction of all the units (40 blocks in total). These 8 blocks also can be adapted as extra housing elements or warehouses for the enlargement elements or/and for the saved belongings of the disaster people. It's an opportunity to have some extra units for different occasions.

In the case of this study, the housing unit structural system is chosen as the LGSF system, which is the system that is suitable for any poor ground conditions. The temporary sites that would be chosen for the disaster occasions are defined to be located nearby the disaster places where mostly in or next to the city centers. The areas that can be reserved for such uses mostly have very bad ground conditions where nothing can be built or they're chosen from productive agricultural sites. The LGSF system is suitable for the poor ground conditions, but the conventional foundation system of LGSF (foundation raft) is not suitable according to the defined temporary site requirements, especially in agricultural sites, so in this project the foundation system had been designed as movable concrete prefabricated modular blocks for not to leave any trace on the site after the temporary period is over.

4.4.2. The Living Conditions of the "Temporary Post-Disaster Housing Unit"

The houses designed in the project are the optimum designs obtained for the "Temporary Post-Disaster Housing Units" with the material that can be provided in Turkey. The materials are chosen to make the best visual effect with the least cost and that maintains the optimum requirements defined in a temporary post-disaster housing unit.

4.4.2.1. The Spatial Characteristics of the "Temporary Post- Disaster Housing Unit"

The spatial characteristics of the designed temporary post-disaster housing units are defined as the living, sleeping, dinning areas, kitchen and bathroom. The living, sleeping and dining areas in all plan types (plan types for 2-3, 4-5, 6-7, 9-10 people) are located in a single volume. In this area mostly the foldable and convertible furniture help the system to be adaptable for living and sleeping in the same place at different time. The dining facility is also done with the plastic foldable tables and chairs in the 2-

3, 4-5 people houses to avoid extra space use for the function. The foldable table and chair system can also be used in the small terrace in front of the houses as well. The kitchens are also a part of the living area, because of the fact that mainly the cooking function won't be needed in the temporary living shelters. The food can be distributed to all people in short period temporary housing.

The main sleeping areas in each unit are separated as well as the bathrooms. These are the two main functions that had been asked for closed single space areas in the requirements. For the 8-9 people house differently from the others 2 more bathrooms are designed.

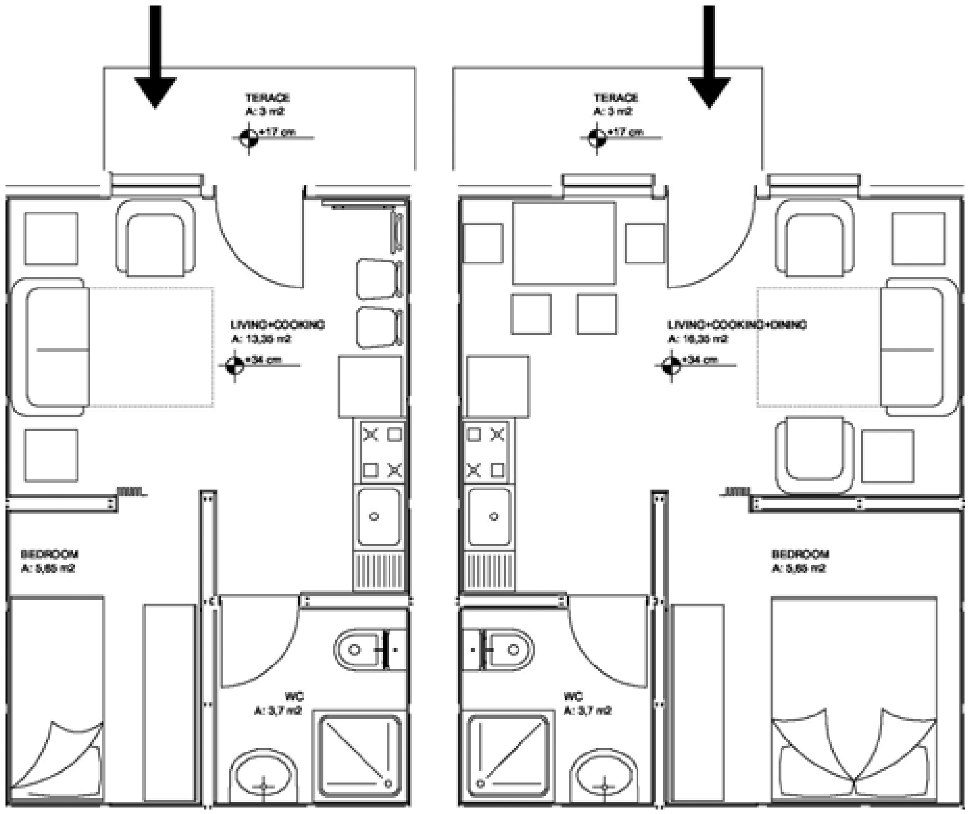


Figure 4.2 Plans for 2-3, 4-5 people houses

4.4.2.2. The Dimensional Requirements for a "Temporary Post-Disaster Housing Unit"

The various standardizations studied on the requirements of the temporary shelters had been analyzed and in the project the house areas were defined as;

- 2-3 people 24 m²
- 4-5 people 30 m²
- 6-7 people 54 m²
- 8-9 people 60 m²

The size of prefabricated materials that was chosen and variability search in study of the houses have defined the final areas. The study of Baradan was also a main guide in the area requirements and in the location of the units in the housing blocks.

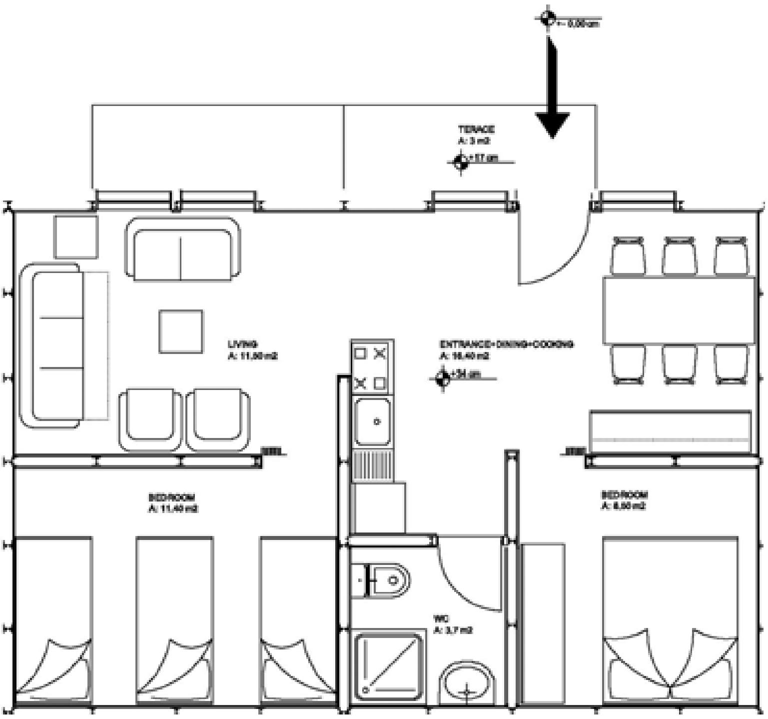


Figure 4.3 Plan for 6-7 people

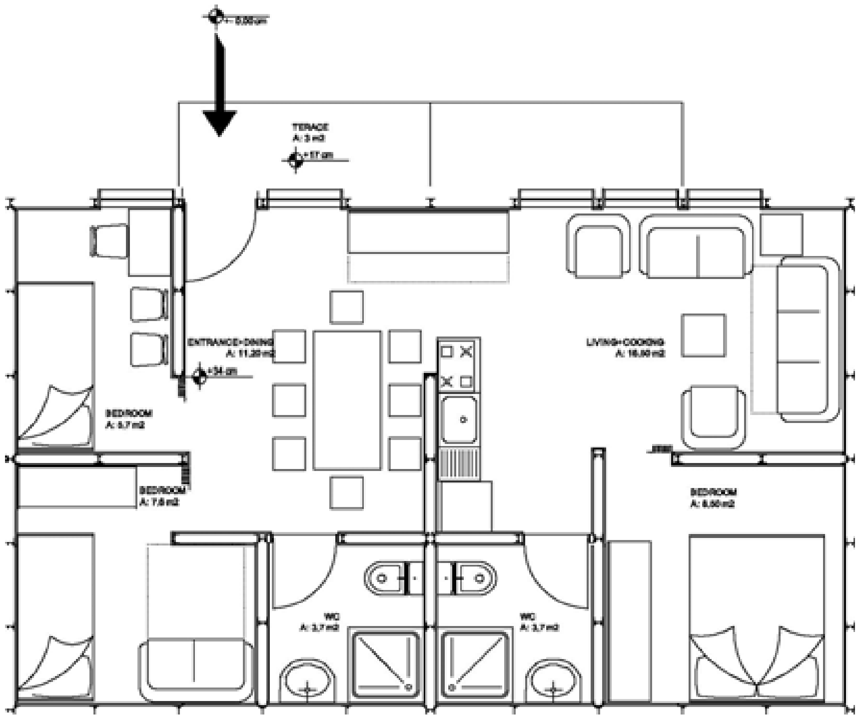


Figure 4.4 Plan for 8-9 people

4.4.2.3. The Comfort Conditions Required in a "Temporary Post-Disaster Housing Unit"

4.4.2.3.1. The Climatic Comfort Conditions

a) <u>Heat Comfort Conditions</u>

In the beginning of the project to obtain the heat comfort condition was a main goal and it had been an important characteristic of the studied project. The temporary post-disaster housing units mostly are not suggested to be heated with extra heating systems, especially in warm regions like Turkey. The winter disasters may cause a need for the heat sources to be placed in the houses designed, but for other season disaster occasions, if the system would be designed as a well insulated one, there won't be any need for heating systems.

The structural material of the designed project, CFS profile is a material that causes heat loss. There may be heat bridges at many points in the system, so the heat insulation of the system is always been designed with extra care, but in the "temporary post-disaster housing" where the structures are mostly light materials, it should be insulated with extra more care. The units are very small and designed as compact volumes, to maintain a good heat condition in the house the structural panels are been covered with polystyrene foam additive aluminum board elements, also an empty space of 3 cm was left in between the panel elements and the outer covering by the help of extra joint elements.

The needed insulation thickness (polystyrene foam) can be calculated by the heat insulation formulas.

- λ of LGSF 48
- λ of glass 5
- λ of aluminum 175
- λ of plaster board 0.035
- λ of polystyrene 0.034
- λ of OSB 3 0.1
- λ of plastic vapor balancing layer 0.06

The defined formulas for calculation are;

$$R = \frac{1}{\alpha_{iç}} + ... + \frac{1}{\alpha_{dış}}$$

$$\frac{1}{K} = R + Yl\dot{I}K = \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + ... + \frac{1}{\alpha_{iç}} + \frac{1}{\alpha_{dış}}$$

$$\alpha = m^2hc^o \big/ kcal$$

The building is thought to be located in the second climate zone of Turkey;

The Heat Insulation Values of the Walls

Data:

Windows: Simple Plastic Windows (90/100 cm)

Doors: Simple Plastic Doors (90/200 cm)

Walls: LGSF Framed walls with polystyrene foam additive aluminum board elements from outside, plaster board from inside (t: 19 cm)

- Total area of the elevations is calculated as 143.6 m² %100
- Total area of the windows is calculated as 12.6 m² %8.8
- Total area of the doors is calculated as 14.4m² %10
- Total area of the walls is calculated as 116.5 m² %81.2

$R_o \min = 1.80$ for 2nd climate zone for walls lighter than 50 kg / m² (Section 4.4.2.4.2, Section 4.5)

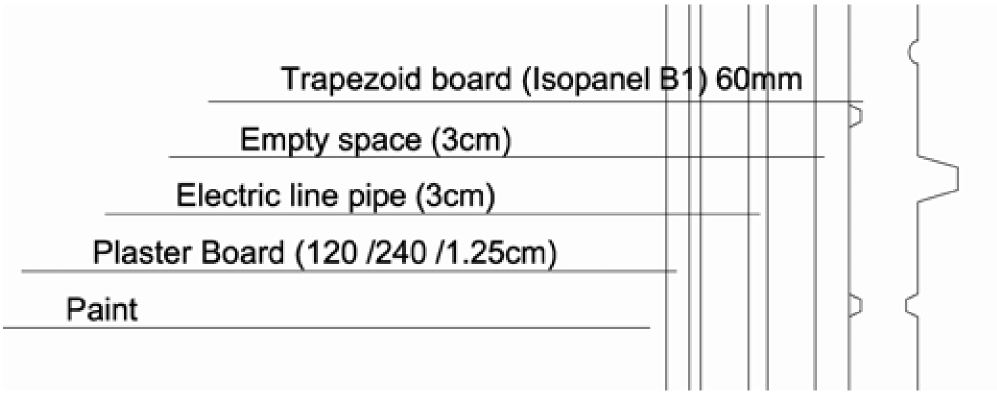


Figure 4.5 Detail of wall construction

$$\frac{1}{K} = \frac{1}{20} + \frac{.001}{50} + \frac{.0013}{.60} + \frac{.06}{.034} + \frac{.003}{48} + \frac{1}{7} = 1.96$$

$R_o \min = 1.80 \leq 1.96$: 60mm polystyrene is enough

$$K = \frac{1}{1.96} = 0.51 \, {}^{m^2hc^o}\!/_{kcal}$$

$$\frac{1}{K} = \frac{1}{20} + \frac{.04}{.18} + \frac{1}{7} = 0.415 \, {}^{m^2hc^o}\!/_{kcal}$$

$$K = \frac{1}{.415} = 2.4 \, {}^{m^2hc^o}\!/_{kcal}$$

For 3rd climate zone K average: $1.15 \, {}^{kcal}\!/_{m^2hc^o}$

$$K_{aver} = (5 * .088) + (.51 * .812) + (2.4 * .1) = 1.0936$$

$1.0936 \langle 1.15 \, {}^{kcal}\!/_{m^2hc^o}$: 60mm polystyrene is even enough for the 3rd climate zone

The Heat Insulation Values of the Roof

Data:

OSB 3 (11mm), vapour balancing insulation layer and polystyrene foam additive aluminum board elements

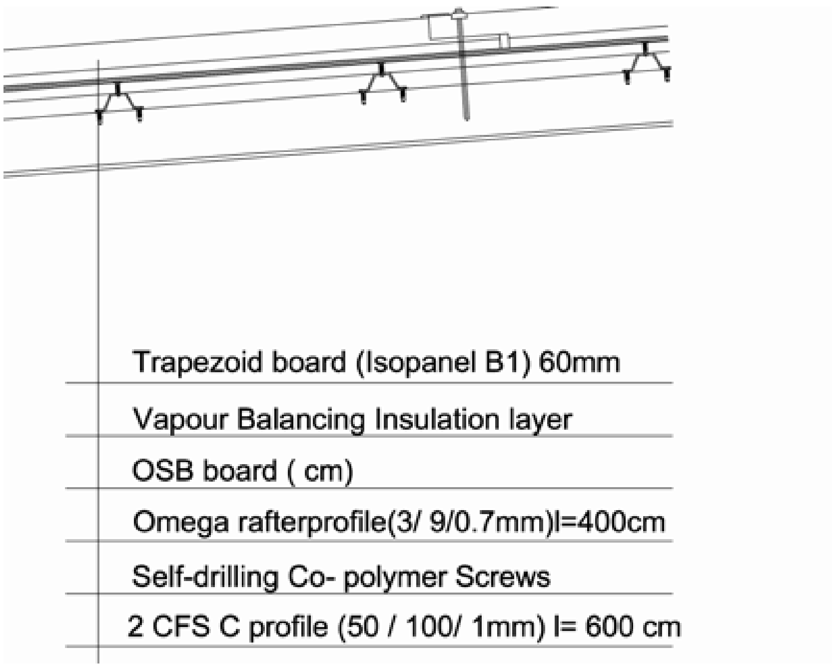


Figure 4.6 Detail of roof construction

$R_o \min = 1.80$ for 2nd climate zone;

$$R = \frac{.011}{.1} + \frac{.O6}{.034} + \frac{.003}{.06} = 1.874$$

$1.874 > R_O \min$: 60mm polystyrene is enough

According to the calculations, 60 mm polystyrene isopanel can make a well-insulated system in walls and roof. The floor system is insulated naturally by the foundation system and the void left in between the flooring and the ground. The well-insulated volumes of the small sized houses can be heated by electrical heaters in the cold days without causing any harm on the people and structure.

As stated in the Baradan's study, in the constructed "temporary post-disaster housing unit" examples after the 1999 earthquake heat comfort conditions are one of the main complaints in common. This part tries to recover the general problem of the temporary shelters on heat conditions. The outdoor covering element can be calculated again for the different climatic conditions on different locations and also the outdoor covering system can be changed with other materials, so various different design looks can be obtained in the future with the flexible system of the new designed structure.

b) *Ventilation Conditions*

Ventilation is as important as obtaining the ideal heat. The units that vary with areas between 24-60 m² and with heights in between 2-2.70 meters are volumes that need to be ventilated every day for maintaining the health conditions. In Turkey conditions, the hot summer days are the time that ventilation has extra importance.

In the designed project, the circulation of air in the house can be obtained by keeping the partition element in between the bedroom and living area open. The combination of the 8 or 4 houses back to back in position, gives the system many advantages like saving elements, easy solution for the infrastructure elements etc., but this back-to-back system of the houses also caused light and ventilation problem at the back parts of the houses. This problem had been solved by a roof adjustment and extra windows, which had been used for the ventilation of the rooms in the middle parts (bedroom & bathroom). These small windows (vent sashes) are placed in the main façade window axes, so the air circulation in the house can be obtained easily when the interior partition elements are open.

c) *Prevention of Humidity*

To prevent humidity is a must for the maintenance of the system and for the health of the people living inside. For the reuse of the elements, the system elements must be protected from moisture.

In this study to avoid humidity the housing systems had been designed as located over the ground level on the foundation elements, which are half grounded. So the ground water and moisture can be kept away from the housing system. To avoid the water leak from the roof and from the foundation-covering panel connection, vapor balancing insulation layers had been adapted on roofs and on the foundation elements.

The temporary post-disaster housing units, which still exist in Adapazarı, are mostly affected by the humid. This study aims to solve the humidity problem in order to maintain the standard comfort conditions and to keep the system for reuse.

4.4.2.3.2. The Optical Comfort Conditions

The daylight is the main need to obtain the visual comfort conditions in a house. In the temporary post-disaster housing units, considering the psychological estate of the victims the daylight should be kept in the houses as much as possible.

In the designed project, the windows are mainly located on the main façade facing the private area preserved for each house. The terrace would help to blur the outside-inside borders and the house can become visually a part of the outside in the hot climates. The housing groups are not planned with openings on each façade. The two façades, which are short in length, are designed as dead walls that give chance for the future extensions. The other two façades (one house façade on each) are designed as 7 windowed (90 /100cm) façades, which allows daylight in. The bedrooms and bathrooms which are not needed to have big windows are placed in the middle areas with small windows to obtain more daylight and to obtain ventilation facilities in the house.

The housing blocks are located with 16m spaces in between which is proposed to be a green space that would increase the visual quality of the site. The fact that interrupts the visual look of the existing "temporary post-disaster housing units" in Adapazarı is the extensions made by the habitants. One of the main goals of this project is to keep extra space and equipments for extensions, so after the needed extensions are done the building site look wouldn't be affected badly in the proposed design.

4.4.2.3.3. The Sound Comfort Conditions

The proposed "temporary post-disaster housing units" are constructed as twin, row houses as explained before. This organization of housing has many advantages, but the sound insulation in between the different housing units should be well made.

The LGSF panel elements are framing elements as it has been declared in the name as well. And the panels' frames are designed as empty elements, the panels that are the separators in between the houses are stuffed with glass wool slab, sound insulation elements in order to maintain the optimum insulation.

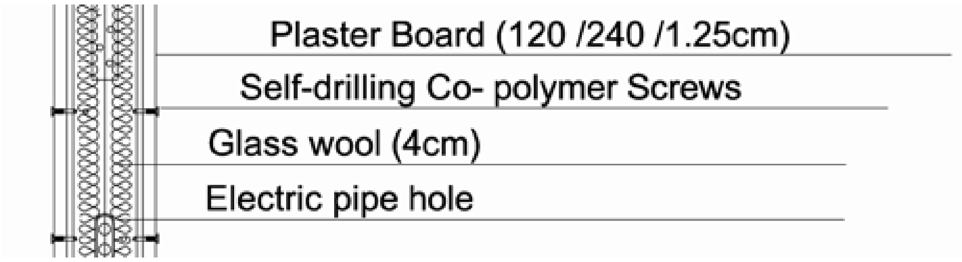


Figure 4.7 Sound insulation layer between two houses

4.4.2.4. The Structural Requirements for a "Temporary Post-Disaster Housing Unit"

4.4.2.4.1. Demount Ability (Availability for Reuse)

In the designed system, the joint elements are chosen as the self-tapping screws. The easiest way to join the cold formed steel profiles to each other and to the other system elements is by using the self-tapping screws. The self-tapping screws can be applied by standard equipment called the screwing gun, by anybody. To remove and refasten the elements by the help of these joint elements is very easy. Considering in mind that each screw opens a small opening on the materials, the exact places of the screws should be defined well in order to keep most of the materials for reuse. The steel connection elements (L shaped angle elements), which are used in; foundation-wall system and wall system-roof connections, are bolted to the CFS profiles and anchorages to the foundation and roof system elements.

The system elements should be combined together with the guidance that will be packed in the packaged boxes as well as the building components. The connections should be made carefully to avoid extra damage and the system should be also removed according to the directions. The most damaged parts; the plaster boards inside, the corner points of some CFS elements should be replaced and the CFS profiles should be re-galvanized by paint before the systems are stored for the second and third disasters. Keeping in mind that the system elements are very light in weight and fragile in this manner, the CFS profiles of the LGSF system of the “temporary post-disaster housing” are not proposed to be used more than 3 times. The CFS profiles can be recycled and they can again be shaped for “temporary post-disaster housing units”.

4.4.2.4.2. Easy and Fast Montage

The montage of the panels designed in this project is simple and very easy, because the weight of the system elements is low. All the elements are designed to be carried by only one or two people and mounted to their place by two or at most by three people in difficult conditions. The modular system in the design helps to rapid up the process. The modular LGSF system gives the chance of easy and fast montage;

- The covering modules of the walls (100/220/6 cm) weigh around 11.5 kg each,
- The other covering modules of the walls weigh around 11-13.75 kg each,
  total weight of wall covering boards: 1513.32 kg
- The roof covering modules (100/300/6cm) weigh 12.8 kg each x76,
- The roof covering modules (100/100/6cm) weigh 4.27 kg each x38,
  total weight of roof covering boards: 1135.06 kg
- The LGSF wall modules (100/200-270 made of 0.15 cm thick profiles) weigh around 20-25 kg each,
  total weight of wall profiles: 4298.59 kg
- The roof’s CFS profiles (5/10/550/0.1 cm C profiles) weigh around 8.5 kg each,
  total weight of roof profiles: 1142.54 kg
- The roof’s Omega profiles (3 /9 / 500 / 0.07 cm) weigh 3.5 kg each x78,
  The roof’s Omega profiles (3 /9 / 400 / 0.7 cm) weigh 2.8 kg each x26,
  total weight of roof omega profiles: 345.8 kg
- The flooring elements, weigh around 23.2 kg per m2,
  total weight of floor profiles: 5291.6 kg
- The OSB and plaster board weights are 4311.65 kg,

The total weight of the system of a “temporary post-disaster housing unit” design is around 18200 kg → per m² 79.8 kg

- The prefabricated concrete base modules (30/50/100) weigh around

  240 kg each x95,
- The prefabricated concrete L base modules (30/50/100) weigh around

  350 kg each x14,
- The prefabricated concrete base modules (30/30/100) weigh around

  140 kg each x40,

Total weight of the foundations is 33300 kg

The foundation modules are heavy and they should be placed by crane, the other elements are easy to be carried, fixed and unfixed. The other modular elements can easily be fixed by the unqualified workmen or by the volunteered disaster people with the help of the instruction sheets, if the connection points on the elements can be high lightened by the different colors of paint. The service channels and pipes are placed in the system after the structural panels are fixed together, before the plasterboards are placed in the interior.

The first eight housing blocks are proposed to be finished in at most 4-5 days, which is a very fast timing for montage. So the emergency shelter need is really been minimized in this project.

4.4.2.4.3. Fast Production

The production of the project should be done before any disaster occasion happens. In order to manufacture the system fast and simply, the choice of materials and material sizes need to be made by the data of the producer companies. For the continuity of the production with the same manufacturing facilities, it’s always better to use the standard materials of the factories. To ask for a different industry for producing “temporary post-disaster housing units” means to leave the industry without working in the other periods. This is not feasible.

The production process of this project can be maintained in the storage points in a special atelier place where most of the elements are transported ready to be installed in the packages. The project can even started to be manufactured today, because all the materials are chosen from the ones that can be produced in Turkey. Only OSB is an imported material in the design.

4.4.2.4.5. Easy Transportation

One of the most important and essential incomes of the design of the project is consideration of how to transport the “temporary post-disaster housing units” to the disaster sites. The project has been studied in the Turkey standards and for solving Turkey’s emergent disaster housing problem, so the transportation had been studied in Turkey conditions as well. The best way to reach any point on Turkey is still by highway. The maximum sized internal vehicles were chosen as the transportation elements. The truck sizes (interior 2.4/2.4/12 m) had been the fact that defines the packaging box element sizes. There are different packages used for different sized elements. Each of the “temporary post-disaster housing unit blocks” (228 m^2) can be transported with two trucks to the site and the foundation element truck can carry the foundations of four blocks all together.

The quality of the packages is also important in the easy transportation of the system elements. The organization of the boxes in the transportation vehicle is a fact and the organization of the elements inside the packages is another fact that defines the best way of transportation. The elements must not be damaged in the packages while stocking and transportation periods, hence to obtain right stuffed packages, the packaging systems should be observed and the insides of the packages should be redesigned in cooperation with a package designer.

4.4.2.4.6. Easy Stocking

The packaging system of the designed project would also help the stocking process. The stocking should be done in big warehouses where standard air circulation and air conditioning facilities can be obtained. The boxes (each weigh: 200-300 kg) should be carried with small carriage cars in the warehouses. No material that may cause termites is used in the system. Only the OSB panels may cause some biological reactions, so they should be stored with extra care.

The package materials are chosen to be hard materials, for the packages to be resistant to strokes and outdoor conditions in transportation. The aluminum sheet covered polystyrene covering & packaging elements can be painted, so the damaged paint on the surfaces of the packaged boxes can also be fixed by painting. The system elements can be kept in the storage for very long times, even longer than the suggested two years because of the durable material structures of the LGSF system.

4.4.2.4.7. Earthquake, Wind & Fire Resistant

The strength of the LGSF systems under earthquake and climatic loading impacts had been studied in detail in the first chapter. The lightweight structure of the LGSF system helps the system to act as an earthquake and disaster shelter. The marketing policies of the LGSF manufacturers of the world mostly depend on this issue. The earthquake resistance of the new “temporary post-disaster housing units” proposal constructed with LGSF system can be examined by AISI Prescriptive method, 2000. The dimensions of the CFS profiles in the LGSF structure are maintained in the light of the prescriptive method from Turkish market products.

The last thing that should be conceived in the building design of the “temporary post-disaster housing units” is the fire resistant building design. The structural material of LGSF system; the CFS elements are incombustible, but the steel is a material that looses its structural strength and leaks at high temperatures. In the studies also the CFS profiles’ strength had been tested under fire conditions and the leak point had been obtained as 180 C. Polystyrene board of 6 cm all over is used to cover the structure in the designed project, but to obtain a feasible system, it has been covered only by 1.2 cm plaster board from inside which is not efficient for fire protection. The panels in between the family housing units, which are stuffed with glass wool slab, are more resistant to high temperatures, but this system also wouldn’t be enough for protection, so in the designed system the most efficient way to be protected by fire is by taking simple precautions. The heating elements used in the houses like ovens, radiators and kitchen and bathroom equipments should be electrical elements.

4.4.2.5. The Durability Conditions Required for a "Temporary Post-Disaster Housing Unit"

The durability of the system depends on the durability of the structural elements. LGSF system elements are long lasting elements and with the used equipment in the designed system, the system can be used within first 8-10 years.

4.4.2.6. The Resistance of the Covering Element Required for a "Temporary Post-Disaster Housing Unit"

The covering elements of the designed system are also the elements used for packaging. By this way, the transportation of the covering elements are solved easily and no extra storage elements are needed. The transportation costs would be minimized, the storage of the packaging elements is solved easily and the water resistant strong covering elements can also protect the elements put in the packages.

The characteristics of the covering elements had been mostly defined in the easy stocking and easy transportation parts. In addition to the given information, the covering elements are chosen from the panels produced for the roof panels. By this way, the water can easily be removed from the outdoor covering. The insulation layer of polystyrene board had been obtained with the heat insulation calculations.

The standard material used in the covering elements used all over the system also makes the package elements to be similar in material. The standardization in the package elements is also good for the temporary demountable design.

4.4.2.7. The Flexibility and Variability of a Temporary Post- Disaster Housing Unit

The flexibility and variability characteristics of the "temporary post-disaster housing units" are the main characteristics that distinguish these houses from the typical permanent housing systems, today.

The housing blocks are designed with 2 dead walls on the same ax. This ax will be the ax of enlargement in the future times of the temporary period. The house plans also designed as convertible plans. A 2-3 people house and a 4-5 people one can be converted into a 6-7 people house or two 4-5 people houses can be converted into a 8-9 people house. These adaptable house plans are the main flexibilities of the system designed.

In case of disaster, the number of people in the "temporary post-disaster housing units" may differentiate by the time. The injured people would come to the site after they've been healed. Also the belongings would be taken to the site and extra warehouse space would be needed for not to overload the small housing units. In the project it's tried to be developed solutions for all the unexpected situations. The variations are defined in the scenario part (Part 4.3.1) with extension system drawings. (Figure 4.12, Figure 4.13)

4.5. Cost Analysis

The cost effective new technology use is a goal of "temporary post-disaster housing". "Temporary housing" is an extra cost for the governments. Especially for countries like Turkey, the most economic "temporary post-disaster housing units" are always been preferred. So although a project fulfills all the demands of a disaster shelter, the most important criteria in choice will be its low cost.

The project proposed in this chapter should be analyzed in cost as well. The 8 unit housing system (house for 30 people is evaluated).

Table 4.1 Weight Analysis of Roof Profiles

Type of Profile	Length of Profiles (m)	Number of profiles	Total Weight of Profiles (kg)
CM10010	5.5	40x2	675.20
CM10010	0.9	40x2	121.54
HS403007	5	78	273.00
HS403007	4	26	72.80
Total			1142.54

CM10010: 50/100/1mm 1.68 kg/m
HS403007: 3/9/0.7mm 0.7 kg/m

Table 4.2 Weight Analysis of Floor Profiles

Type of Profile	Length of Profiles (m)	Number of profiles	Total Weight of Profiles (kg)
CM10020	5.5	86	1541.03
CM12020	5.5	86	1763.82
CM10020	.55	517	926.41
CM12020	.55	517	1060.34
Total			5291.60

CM10020: 50/100/2 mm 3.258kg/m
CM12020: 50/120/2 mm 3.729 kg/m

Table 4.3 Weight Analysis of Wall Studs

Type of Panel	Length of Profiles (m)	Total Weight of Profiles (kg)	Total Weight of Panel (kg)	Number of Panels	Total CFS Weight of the Panels (kg)
Panel No: 1	6.78 (CM10015)	16.77	22.43	6	134.58
	2.03 (CM12015)	5.66			
Panel No: 2	7.02 (CM10015)	17.36	23.02	10	230.20
	2.03 (CM12015)	5.66			
Panel No: 3	7.25 (CM10015)	17.92	23.58	10	235.80
	2.03 (CM12015)	5.66			
Panel No: 4	7.49 (CM10015)	18.49	24.15	18	434.70
	2.03 (CM12015)	5.66			
Panel No: 5	7.71 (CM10015)	19.07	24.73	14	346.22
	2.03 (CM12015)	5.66			
Panel No: 6	6.15 (CM10015)	15.2	15.20	14	306.10
	2.05 (CM12015)	5.66			
Panel No: 7	6.78 (CM10015)	16.77	33.33	4	133.32
	2.03 (CM12015)	5.66			
	9.9 (WB15)	10.9			
Panel No: 8	7.71 (CM10015)	19.07	30.67	4	122.68
	2.03 (CM12015)	5.66			
	5.4 (WB15)	5.94			
Panel No: 9	6.15 (CM10015)	15.2	25.81	4	103.24
	2.05 (CM12015)	5.66			
	4.5 (WB15)	4.95			
Panel No: 10	6.67 (CM10015)	16.49	32.92	4	131.68
	2 (CM12015)	5.65			
	9.8 (WB15)	10.78			
Panel No: 11	6.67 (CM10015)	16.49	27.53	4	110.12
	2 (CM12015)	5.65			
	4.9 (WB15)	5.39			
Panel No: 12	6.67 (CM10015)	16.49	22.14	8	177.12

	2 (CM12015)	5.65			
Panel No: 13	6.9 (CM10015)	17.06	28.36	14	397.04
	4 (CM12015)	11.03			
Panel No: 14	4.9 (CM10015)	12.59	21.07	8	168.56
	3 (CM12015)	8.48			
Panel No: 15	1 (CM10015)	2.47	8.12	14	113.75
	2 (CM12015)	5.65			
Panel No: 16	1.5 (CM10015)	3.71	9.36	24	224.69
	2 (CM12015)	5.65			
Panel No: 17	6 (CM10015)	14.84	20.49	19	389.31
	2 (CM12015)	5.65			
Panel No: 18	7.35 (CM10015)	18.18	23.83	14	333.62
	2 (CM12015)	5.65			
Panel No: 19	7.59 (CM10015)	18.77	24.42	8	195.36
	2 (CM12015)	5.65			
Panel No: 20	6.12 (CM10015)	15.13	22.76	8	182.08
	2.7 (CM12015)	7.63			
Panel No: 21	5.4 (CM10015)	13.35	21.83	8	174.64
	3 (CM12015)	8.48			
Total				217	4298.59

CM10015: 50/100/1.5 mm 2.473 kg/ m
CM12015: 55/120/1.5 mm 2.826 kg/ m

- Total weight of cold formed steel profiles used in the project is 10732.73 kg

  The cost of profile with workmanship and equipment is 2.3 $ per kg

  Total cost is: 24685.3$

Table 4.4 Weight Analysis of the Wall Covering elements

Type of Panel	Area of panel (m2)	Weight of Isopanel (kg)	Weight of Plaster Board (kg)	Number of Panels	Total Weight of Coverings of Panels (kg)
Panel No: 7	2.26	9.65	20.34	4	119.96
Panel No: 2	2.34	9.99	21.06	4	124.20
Panel No: 3	2.45	10.46	22.05	4	130.04
Panel No: 4	2.50	10.68	22.50	4	132.72
Panel No: 8	2.57	10.97	23.13	4	136.40
Panel No: 9	2.05	8.75	18.45	4	108.80
Panel No: 10	2.22	9.48	19.98	4	117.84
Panel No: 11	2.22	9.48	19.98	4	117.84

Panel No: 12	2.22	9.48	19.98	8	235.68
Panel No: 13	1.32	5.64	11.88	14	245.28
Panel No: 14	0.42	1.79	3.78	8	44.56
Total					1513.32

- Total area of wall covering boards (Isopanel 6cm) is 114.04 m²

  The cost of wall coverings with workmanship and equipment is 13$ per m²

  Total cost is: 1482.5 $
- Total area of roof covering boards (Isopanel 6cm) is 264 m²

  The cost of roof coverings with workmanship and equipment is 13$ per m²

  Total cost is: 3432 $
- Total area of indoor wall covering boards (plasterboard) is 136.85 m²

  The cost of wall coverings with workmanship and equipment is 12.2$ per m²

  Total cost is: 1669.5 $
- Total area of OSB 3 (122/244cm t:18mm) boards are 74 pieces

  The cost of one OSB 3(18mm) with workmanship and equipment is 6.7 $ per m²

  Total cost is: 495.8$
- Total area of OSB 3 (122/244cm t:11mm) boards are 80 pieces

  The cost of one OSB 3(18mm) with workmanship and equipment is 5.1 $ per m²

  Total cost is: 408 $
- Total area of Vapor Insulation Layer 266 m²

  The cost of Vapor Insulation Layer with equipment is 2 $ per m²

  Total cost is: 532 $
- Total area of glass wool (5cm) 80 m²

  The cost of glass wool (5cm) with workmanship 2.5 $ per m²

  Total cost is: 200 $
- Total area of ceramics 29.6 m²

  The cost of ceramics (10/10 cm) with workmanship 10 $ per m²

  Total cost is: 296 $

- Total area of lynolium covering 206 m²

  The cost of ceramics (10/10 cm) with workmanship 6.7 $ per m²

Total cost is: 1380.2 $

- Total cost of windows and doors — Total cost is: 2721.1 $

  Total cost of bathroom equipments — Total cost is: 492 $

Total cost of the housing system without foundation elements:
37794.4 $+Taxes (KDV)

- Total number of (50/30/100 cm) prefabricated concrete foundation elements

  95 pieces

  The cost of one (50/30/100 cm) block with workmanship and equipment is 15 $

  Total cost is: 1425 $

- Total number of (50/30/100 cm)L prefabricated concrete foundation elements

  14 pieces

  The cost of one (50/30/100 cm) block with workmanship and equipment is 22 $

  Total cost is: 308 $

- Total number of (30/30/100 cm) prefabricated concrete foundation elements

  40 pieces

  The cost of one (30/30/100 cm) block with workmanship and equipment is 16$

  Total cost is: 640 $

Total cost of the housing system witht foundation elements:
40167.4 $ + Taxes (KDV)

CHAPTER 5

EVALUATION & CONCLUSIONS

5.1. Evaluation of the Strengths and Weaknesses of "Temporary Post-Disaster Housing Unit" Project Constructed with LGSF system

It's better to summarize the strong and weak points of the design on "temporary post-disaster housing" constructed with LGSF system after the evaluation of the system according to the requirements defined for a "temporary post-disaster housing unit" in Chapter 4.

The new design opposes the standard optimum requirements defined for the "Temporary Post-Disaster Housing Unit" design for disaster occasions;

a) The building site is defined and studied with all the characteristics and service facilities.
b) The houses are designed in accordance with the optimum living conditions;

- The space arrangements in the house are done with the overlapping function planning.
- The areas of the houses are defined in harmony with the habitants (differentiates between 7-12 m2 per person).
- The living comfort conditions for a "temporary post-disaster housing unit" are obtained. For heat comfort, insulated thick panels are used; for ventilation, windows are put facing each other; for preventing humidity, the structure is put up on the foundation module skirting elements and extra insulation layers are used.
- The structural comfort conditions for a "temporary post-disaster housing unit" are obtained. For demount ability, the modular panel systems are been used; for easy and fast montage, the elements in the system are chosen from light weighed ones; for fast production, the system is been made of standard materials manufactured in Turkey; for easy transportation, the system elements are packed

in the boxes which are also made with outdoor covering elements of the system according to the sizes of the transportation vehicles; for easy stocking, the system elements have been stored packed and they'll be fixed and repacked after the temporary period is over; for earthquake, wind and fire resistant design, all the system elements are prefabricated to obtain the accurate elements, the foundation system is studied in detail and solved with the pre-stressed cable elements, LGSF system had been used with extra bracing elements at the needed points for loads of the wind, extra precautions are used for the houses to be protected from fire.

- The LGSF system proposed for the "temporary post-disaster housing unit" is a durable one and all the extra needed components are chosen to support the long-living character of the system.
- The covering elements are chosen from hard aluminum covered polystyrene boards which may resist strokes and hard weather conditions as the façade covering elements and package covering elements.
- The system is a flexible and variable system in planning which makes the future adaptations and extensions possible.

The most original and unique of this project is its new approach in LGSF system in Turkey. The reuse of the LGSF components has never been applied in Turkey.

The strong points of this project are its lightweight and strong structure that's been supported by its symmetrical design, flexible plan organizations and adaptation of new covering elements which make the system suitable for any location in any weather condition. It is better than many of the examples with its foundation system which takes the house blocks up from the ground level as a skirting element, with this little detail, all the housing block is bordered as if it sits on the ground level (no obstacles can go under the system) and the main infrastructural elements can be hidden under the system elements. The outer look of the system is also a strong point, which would convince the victims to live in with its durable and familiar look. Many other strong points are defined in the evaluation part and it can be observed that these are the facts of the used construction system (light gauge steel framing). The cheap cost of the system offers feasibility for application.

The weak points of the design can be stated as; the LGSF systems do fail under the fire occasions which force the system users to be careful. The other weakness of this design is the foundation system. Although the foundation elements are beneficial in the design, these elements need to support the structural wall systems all under, which causes a lot of material to be used. In most of the other "temporary post-disaster housing unit" systems, the pointed footing elements are enough for maintaining the stability of the system. The single storey LGSF structures don't need thick foundation elements, but the suggested foundation for such applications is the foundation raft system, which is not suitable to be put on a temporary building site. So the prefabricated concrete foundation system had been derived but to place the modular elements a crane is needed and this foundation system adds extra costs in the production and application of the whole system.

5.2. Comparative Evaluation of "Temporary Post-Disaster Housing Unit" Project Constructed with LGSF system with "İzmit Derince Prefabricated Container Houses"

"After the 17th of August 1999 earthquake İzmit Bay Earthquake, one of the international help services, World Relief had bought 700 module type containers from a firm named as Prefabricated Building Firm, for to be used in the Derince area of İzmit." (P.110, Baradan, 2002).

Photo 5.1 İzmit Derince Prefabric Quartier (Prefabrik Yapı)

The module container is (7/3/2.6m) in size. The house area is 21 m² and the house has 2 bedrooms, a bathroom and an open system small cooking area. The module is a prismatic one and it is made of Steel sheet profiles as well.

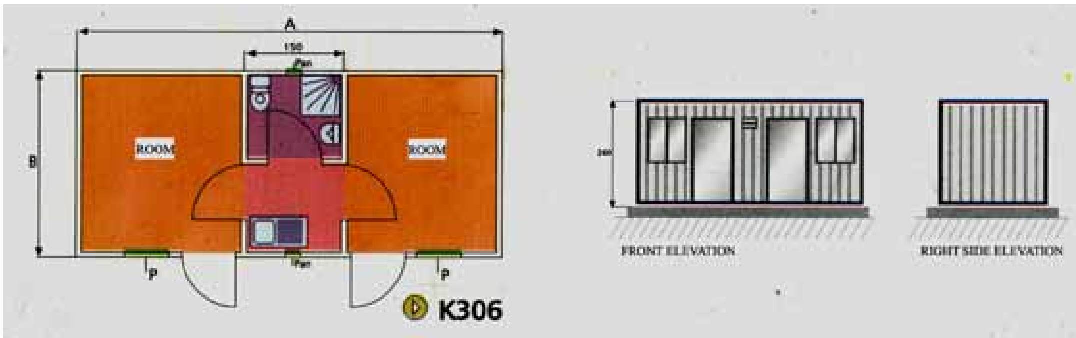


Figure 5.1 Plans and elevations of the container house

In the container, the prefabricated trapezoid sectioned, sheet bodied 1.25/2.5/1.0m sized panels are used in the wall elements. 0.80 mm thick DKP trapezoid sheet has been used in the wall systems. For heat insulation 40 mm polystyrene foam board and 12 mm chip cement board are used. The interior coverings are been mounted on the 30/50/2 mm wooden frame. The outside of the walls is covered with industrial undercover and half synthetic oil paint. The interior walls are sandwich panels made of two 12 mm of white pressed chipboard and 50 mm of polystyrene foam board. The chipboard elements are attached to 30/50/2 mm wooden frame and painted.

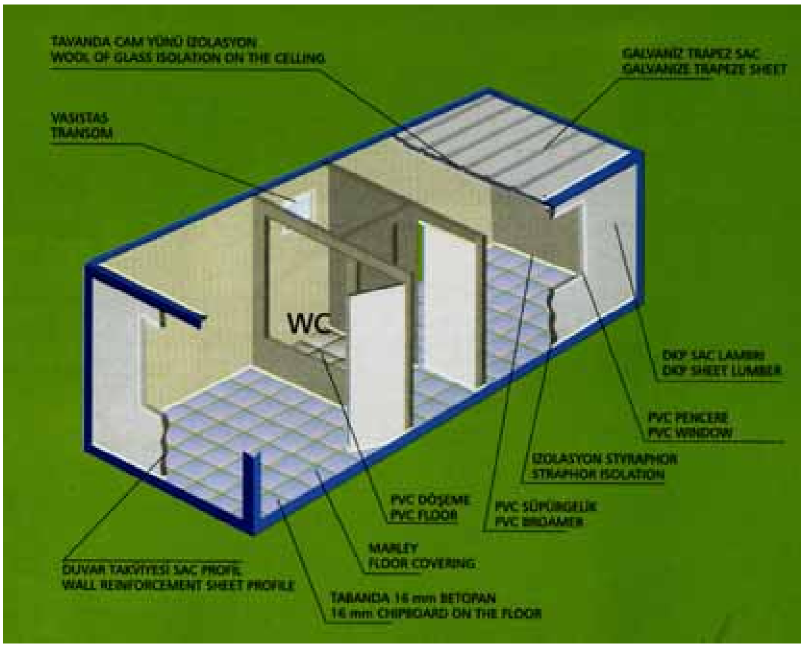


Figure 5.2 The structure of the module of (Prefabrik Yapı)

On the roof of the module, for heat insulation 40 mm thick glass wool; for ceiling covering 12 mm chip cement board/ chipboard or PVC has been used. For roof covering, 0.55 mm thick trapezoid galvanized metal sheet elements have been used.

For flattening the ground, rubble concrete is done in the size of the container without any iron addition. The montage is very short, they're just placed to their defined point by the help of a crane and the installation element connections are done. For the transportation and stocking again the cranes are needed. The steel cables are tied to the hidden irons placed in the corners of the container and the crane moves the module.

According to the evaluations of Baradan, the container type constructions are the ones, which are most satisfactory living units for the users. There are two types of container systems used in the temporary period of İzmit Bay Earthquake and the one that has been evaluated in this section is the second most satisfactory example. It has nearly the same satisfaction value with the most satisfactory one, which is very close to the satisfaction criteria of an optimum "temporary post-disaster housing unit".

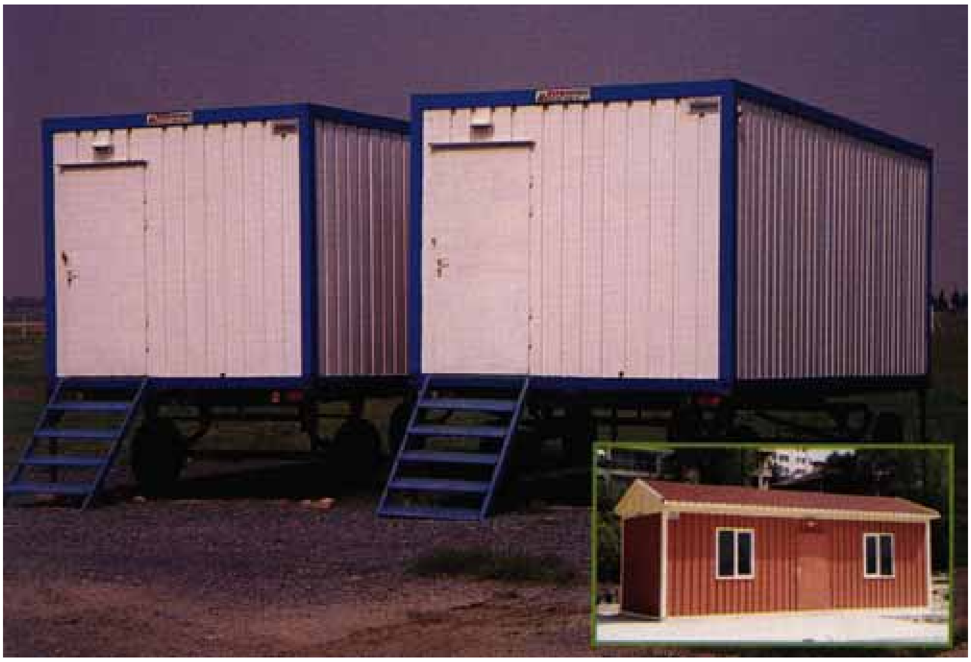


Photo 5.2 Two types of container houses; (Demountable and module type)

"Denizfeneri Container Houses" are chosen as the example to compare with the case study project of this thesis, because the sizes of the houses are similar and the current cost and weight values of the containers can be obtained.

The comparison of cost and weight will be done which are quantitative and which can easily be compared. The cost is the main concern of the Turkish government and also many authorities and the weight is a characteristic that affects many of the requirements of a standard “temporary post-disaster housing unit”. As defined in the end of Chapter 3; Lightness in weight causes the LGSF system to be an earthquake resistant, easy and fast mountable, easy portable and storable, fast produced and constructed, easily prefabricated and mass produced system which is suitable for additions and poor ground conditions, so the lightness in weight kind of fulfills the main properties required in a temporary post disaster housing unit.

The cost of the 21 m² container is 4490 $ + the taxes (KDV) without the foundation. The cost per m² is calculated as 213.8 $. The total weight of the container is defined as 2000kg, where the weight in 1 m² is calculated as 95.24 kg.

The cost of the “temporary post-disaster housing unit” constructed with LGSF system is calculated as 37749 $+ the taxes (KDV) for 228 m², 8 housing units. The cost per m² is calculated as 165.6 $. The total weight of the system is calculated as 18200 kg without the foundation elements, where the weight in 1 m² is calculated as 79.82 kg.

When the two “temporary post-disaster units” are compared it has been seen that the new proposal constructed with LGSF system is lighter in weight and lower in cost. The lightness in weight is not very different in numbers because the structural elements are similar, but the way to break apart a container into smaller pieces like the proposed project is not possible. Demountable containers can only be pulled apart into a few pieces whereas the adaptability and variability chances are not possible. Also the main difference of a container from the proposed project is the volume it occupies while transportation and stocking stages. The transportation and storage of containers needs much more space than the pack able LGSF temporary post-disaster housing units.

Photo 5.3 Section of a demountable container

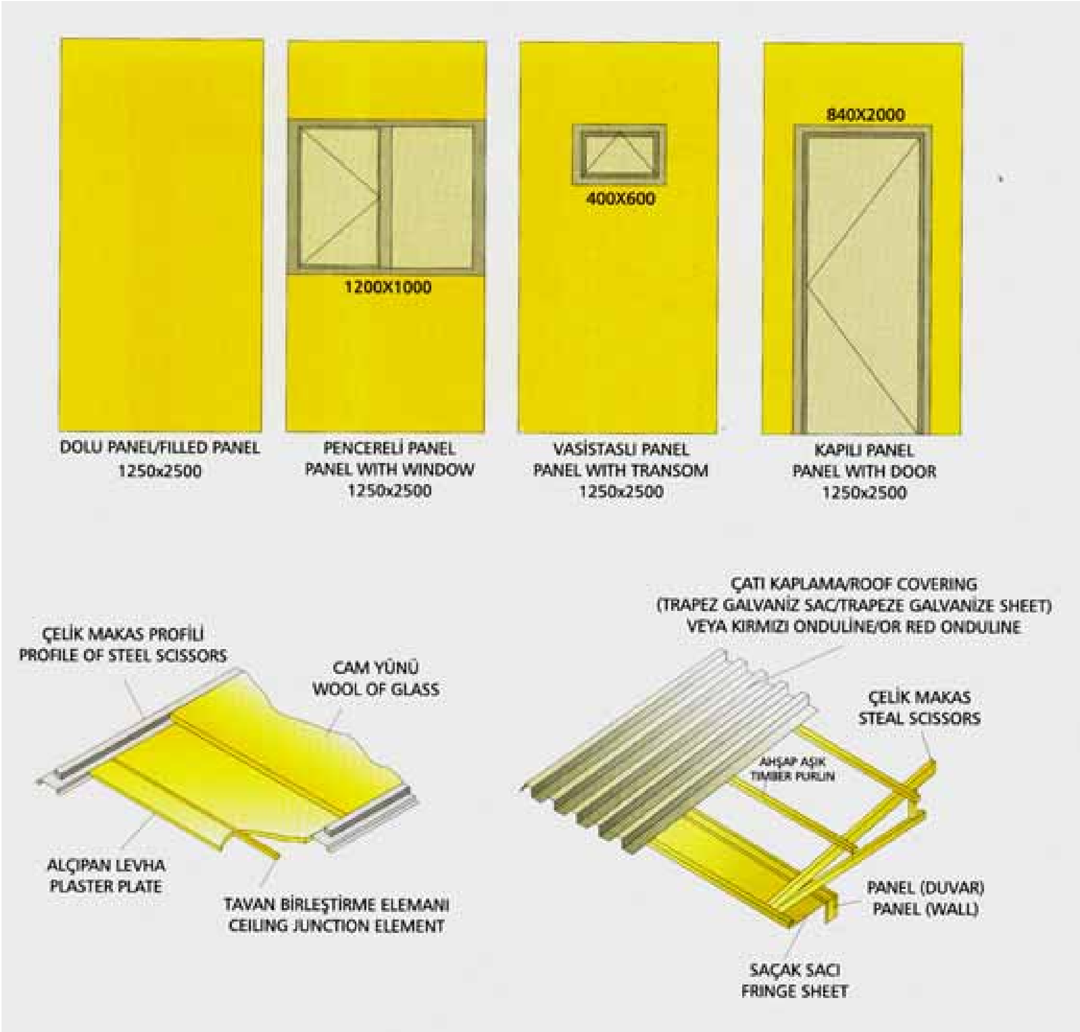


Figure 5.3 The structure of demountable container

The foundation system needed in the new designed project gives extra loading on the system, but it is better than rubble concrete under the container system which stays on the ground after the demount of the units. In the proposal constructed with LGSF, it was also possible to build a foundation raft system under which would be very easy to do, but a new foundation system had been developed in order not to leave any traces on the temporary site. For container system if a portable foundation system is studied, a new comparison may be done again with the two again to see whether there would be any changes in the comparison or not.

Photo 5.4 The two different basement layer under the container modules

5.3. Conclusion

The first part of the study mainly questions one of the new structure systems. Examination of Light Gauge Steel Framing system has been chosen because it was one of the fast developing structural systems in the world's building market. The LGSF system is an affordable system that can be constructed in just a few days. These two main facts of the system are forcing especially the manufacturers to search on the new alternative structural formulas of the LGSF system. The new trends in the world building market are;

- Using LGSF standard modular units in multi-storey apartment blocks by the help of steel structural connection elements.
- Selling LGSF housing packages to be implicated anywhere on the world.
- Making the engineering projects of given architectural designs of buildings up to three storey with the standard profile sizes of the engineering company.
- Making extensions to existing different structures with LGSF structures.
- Making restoration of the old building with small additions and interior rehabilitations with the CFS profiles.
- Structural designing of roof and penthouse elements with LGSF.
- New canopy, balustrade and accessories designs using CFS profiles.
- Regenerating the standard LGSF residential structures with extra different structural system elements.
- To spread out the LGSF prefabricated units and industrial buildings.

This study is mostly focused on Turkey. The main reason of choosing the LGSF system to develop a new "temporary post-disaster housing unit" design among many other new construction systems is the main structural characteristics of the system as well as the fast acceptance and development of this structural system in Turkey. The first projects of the LGSF system had their start out in 1999. Today there are around 50 building companies that build LGSF structures, mainly with the materials that had been designed and manufactured in Turkey. There are many ongoing projects at the moment and they increase in numbers day by day. The proposed project in this study helps us to understand the LGSF construction market opportunities better. The latest trends of Turkish LGSF building market for the moment are;

- The marketing of the typical housing and industrial single storey building models, ready to be implicated with the standard profiles of the engineering company.
- Making the engineering work of the pre-designed house and industrial building designs and marketing them with the standard profiles of the engineering company.
- Attic additions

The development of the Turkish building market is the adaptation of the other big enterprises of the world. The adapted LGSF housing models are not different in plan and shape from the other typical house designs constructed with the conventional methods. The only difference at the moment is the problems faced with the new system are harder to be recovered in Turkey, so the badly constructed examples cannot be rehabilitated. Using accurate material, pre-designed, examined products and details are important in the market of Turkey, because of the experience is fairly new.

The LGSF system can challenge various new uses of the system for Turkey example. The main alternative uses can be;

- Using the system in modular multi-storey apartment blocks: This may give the chance of fast and clean construction process in the dense urban areas where building a construction is difficult.

- Using the system as an extension element as well as additions on top of different structures.
- To build the interior spaces and restoration projects with LGSF.
- Use of CFS profiles in canopies and building accessorizes.
- Use of the LGSF prefabricated systems; “A Temporary post-disaster housing system”

The new “temporary post-disaster housing unit” design proposal has been evaluated in the previous parts of the chapters and according to the results; LGSF system is a suitable system for “temporary post-disaster housing unit”. According to the comparative evaluation; it is cheaper and lighter than the most satisfactory built “temporary post-disaster housing unit” example in Turkey. These are the facts that push the new proposal a step forward in between the other constructed “temporary post-disaster housing unit” examples of Turkey.

The new “temporary post-disaster housing unit” project and other proposed alternatives can be designed with the collaborative studies of architects, engineers and manufacturer companies in order not to cause any future problems. The system is not a system to cause any problems, if the system details are solved in the pre-design process, so the collaboration should start from the beginning and continue until the end of the construction process.

The experience in constructing the LGSF system and design quality of the works done with this system can increase rapidly by the collaborative studies and researches, otherwise the typical ordinary, self-repeating examples of LGSF systems would grow more in numbers, in Turkey. Then the new system approaches wouldn’t be accepted as interesting and challenging design incomes for the designers. Design inclinations should shape the marketing of LGSF after this level, in order to balance the similar standard works done on the subject with some unique examples.

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APPENDIX A

THE DEFINITION OF STEEL AS A CONSTRUCTION MATERIAL

Steel is a material present in the structure of virtually all works of 20th-century architecture: in the connectors, plates, nails, bolts, and screws of timber floors and frames; in the deformed bars hidden within the cement and stone matrix of reinforced concrete; and in the hot-rolled wide-flange columns and beams characteristic of steel skeletal frameworks. Today it is also the basic elements of the Light Gauge Steel Framing systems. While the history of steel as a building material can be traced back at least to the fifth century B.C., the potential to revolutionize the whole process of steel production and form of steel building was in many ways already evident in the 19th century, it is in the 20th century that the architectural expression of steel was most thoroughly explored.

The chief ingredient of the metals known as iron and steel is the chemical element *iron* (ferrum), from which iron-based alloys get the generic name, *ferrous metals*. The term *ferrous* is derived from the Latin word ferrum, meaning iron.

Structural steels, which are used as profiles in most of the buildings, are "mild steels" which have a carbon content of around 0.23%. Mild steel is similar in structure to wrought iron, except that is melted and poured into billets that can be cooled, re-heated and rolled into shape. Because of its greater strength in both tension and compression, steel has replaced wrought iron for most construction purposes. Steels can be produced with a remarkable range of properties through the addition of only 2 or 3 percent of other elements. The amount of carbon still largely governs the strength of the steel.

The structural steel profile elements are mostly manufactured by hot-rolling manufacturing technique. Hot-rolling is a forging process in which hot billets of steel are passed repeatedly between profiled rollers to produce straight elements, which have particular shapes and size of cross-section. Several sets of rollers are normally required to transform a rough billet into a finished element with a cross-section, which has satisfactory structural properties. Most sets of rollers are capable of producing only one cross-section weights within a particular overall cross-section size.

Steel manufacturers produce a limited range of cross-sectional shapes by this process; the principal ones are as follows; I sections, H sections, U sections, channel and angle sections, hollow sections.

There are four broad and sometimes overlapping classifications of steel used in the new construction trends; *carbon steel, alloy steel, high strength low alloy steels* and *stainless steels*.

The classification of steels is complicated by many factors that govern their physical properties. Complete identification of a steel element requires four specifications as; method of manufacture, heat treatment, chemical composition and reference to a well-known standard.

1. Carbon steels: Steel containing over 95% iron, not over 2% carbon is classed as carbon steel. These are usually classified according to their carbon content, the more the carbon amount, the stronger, harder and stiffer is the steel. Carbon steels are also less ductile and more brittle.

2. Alloy steels: Much of the steel used for construction is low (mild) to medium carbon steel that is though, strong and easy to work. Alloy steels are usually designated by the element or elements from which the alloy derives its particular characteristics. If alloying elements are added they then become alloy steels. The tension strength of the steel alloyed with silicium, vanadium and cromium alloyed steels increases the heat and corrosion resistance of steel. Nickel is added to cromium-alloyed steel in order to form stainless steel. Nickel alloy also increases the lengthening data of the material. Manganese increases the friction resistance, also copper and molibden cause resistance to chemical corrosion.

3. High Strength- Low Alloy Steels: A recent development in steel construction has been in the use of a group of patented alloy steels classed as high-strength low-alloy steels, sometimes called weathering steels. Because of their strength they can be used in thinner sections to reduce weight or in the same thickness as carbon steel to support heavier loads. These steels can be easily fabricated by shearing, cutting, forming, punching and welting.

4. Stainless Steels: The corrosion resistance of iron is improved as increasing quantities of chromium are added. At 11.5% there is sufficient chromium to form an inert film of chromic oxide over the entire metal surface and the steel is considered stainless. The film of oxide varies in composition from alloy to alloy and with different treatments, such as hot rolling, cold working and heating. Stainless steels have low heat conductivity but high expansion with changes in temperature.

APPENDIX B
COLD FORMED STEEL PRODUCTION

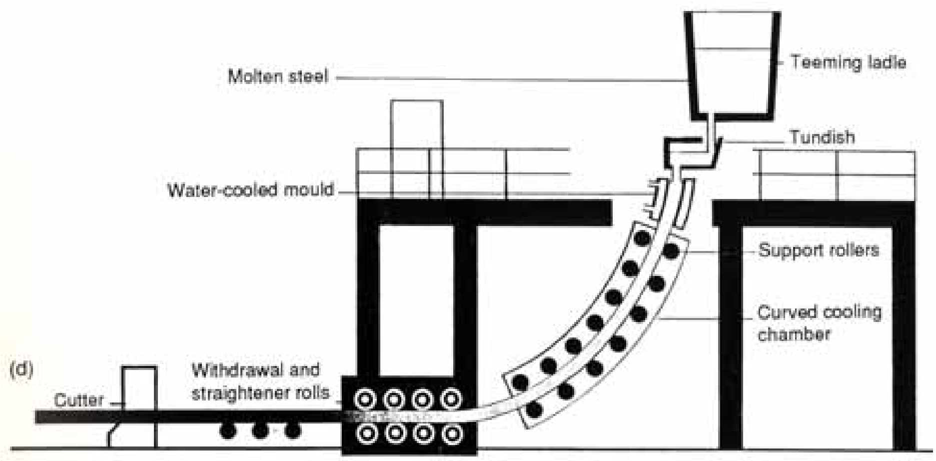

Figure B.1Cold formed steel production

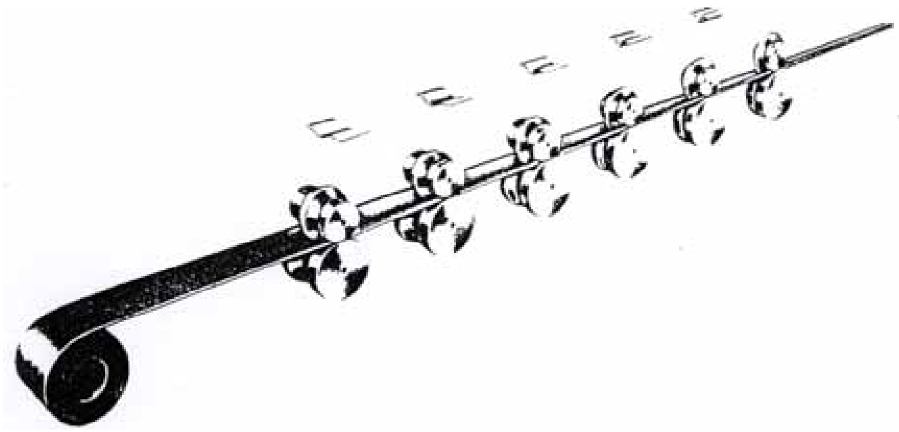

Figure B.2 Cold rolling a section. Strip, from a coil is progressively formed by rolls to achieve the final shape

Photo B.1 Akşan CFS Profile Factory, Çerkezköy İstanbul

The more common manufacturing method of cold-formed sections is the roll forming process without any heat treatment. In roll forming, the strip steel passed through a series of rollers, which changes its shape, the number of rollers, required (5 to 30) depending on the complexity of the shape of the section. The overall length of the forming machine can be over 30m. The section may be cut to length before of offer passing through the rollers. This operation is computer controlled and highly accurate. Holes can also be punched for bolt holes and services before the section is formed. Light gauge steel shapes are formed from flat rolled carbon steel that usually should have the minimum yield point of 40,000 psi. Carbon content is not specified, as mechanical property specifications are the controlling factor.

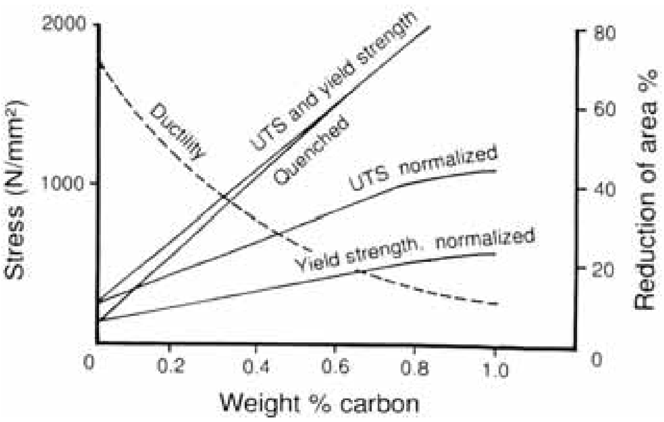

Figure B.3 Effect of carbon on the strength and ductility of plain carbon steel.

The other manufacturing method is press breaking in which smaller lengths are bent to shape in a computer controlled brake press. This technique is generally only appropriate for simple sections in lengths typically up to 6m. The LGSF structural members (CFS: Cold Formed Steel profiles) are maintained by these two manufacturing methods.

Other structural members such as lattice trusses can also be made from cold-formed sections connected together by welding or press-joining. These members may subsequently be galvanized by hot dipping, or painted, if corrosion protection is required. Alternatively, they may be fabricated from pre-galvanized sections, the joints being welded and then the system is zinc painted to prevent corrosion, or after galvanizing connected using screw fixings.

The light gauge steel shapes can be used for spans up to 32'-0'', using the heaviest gauge with 12'' o.c. spacing, where the total safe load does not exceed 98lb. per sq. ft. (NAHB Research Center, 1994)

The Material Characteristics (Technical Properties) of the Light Gauge Steel Elements

There are many parameters involved in the design of cold-formed steel sections and this makes the process complex to overcome. The complete design of cold-formed steel is mainly based on the experimental studies rather than the analytical ones.

Cold-formed sections are usually thin and they often have relatively high width to thickness ratios. Thin elements may buckle locally if they are subjected to compression and several design problems arise from the use of these thin sections different from those of hot rolled sections. The overlap of the structural characteristics of cold-formed sections with hot rolled sections starts around 4.0 mm. (CIPF, 1992)

Sheet steel element used in forming the cold formed steel profiles

Sheet steel used in cold-formed steel sections are produced by cold reducing from hot rolled coil steel. The desired widths, lengths, thicknesses, and shapes are manufactured by a series of roll forming dies as explained before. “The thickness of steel sheet can be referred to by gauge, which typically ranges from 10 to 25. The lower the gauge, the thickness of the material is more (table 1). Interior partition wall studs are typically 25 gauge while load-bearing wall studs are usually 20 or 18 gauge.” (NAHB Research Center, 1994, P.24)

Table B.1 Properties for selected Gauges of Steel Sheet

PROPERTIES FOR SELECTED GAUGES OF SHEET STEEL

Nominal Gauge	Allowable Thickness (inches)	Weight (pounds per square foot)	Color Code (ASTM C955)
10	0.1265-0.1425	5.625	-
12	0.0966-0.1126	4.375	Red
14	0.0677-0.0817	3.125	Orange
16	0.0538-0.0658	2.500	Green
18	0.0428-0.0528	2.000	Yellow
20	0.0329-0.0389	1.500	White
22	0.0269-0.0329	1.250	-
25	0.0179-0.0239	0.875	-

The strength of cold-formed sheet steel comes from the thickness of the material and how it is shaped. When a sheet is formed into a “C” shape, its bends act as stiffeners and increase the strength of the sheet many times over (see Figure 2.4). Strength-to-weight ratios can be highly favorable.

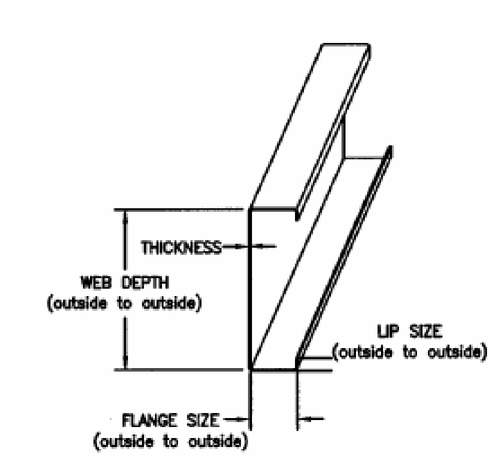

Figure B.4 C shaped CFS Profile

The most important properties of structural cold-formed steel are its yield point, tensile strength, stress-strain characteristics and influence of cold forming on these properties. Ductility and durability are the factors that should also be considered.

Yield Point, Tensile strength and Influence of Cold Forming

The yield points of steel sheets range from 170 to 480 N/mm². Steels that are cold reduced show gradual yielding. The ultimate tensile strength of the steel sheets or strip used for cold-formed steel sections has little direct relationship to the design of such members. The load carrying capacities of cold-formed steel members are usually limited by yield point or buckling stresses that are less than the yield point. The exceptions are bolted and welded connections where stress concentrations may occur and the consideration of tensile strength of the material may be essential. The ratios of tensile strength to yield point generally range from 1.17 to 2.22. (Yu, 1985)

During cold forming process, deformation of the steel takes place within the proximity of the bend. Within the deformed zone, yield point and tensile strength of the steel increases due to strain hardening and strain aging effects. The increase in the yield strength by cold working may be significant for highly stiffened sections with many bends. (Rhodes, Lawson, SCI 1992). The material in the flat parts of the cross section is stronger, since the material in the corners of a section is cold worked to a considerably higher degree. Using a weighted average may approximate the actual yield strength.

Modulus of Elasticity

The modulus of elasticity usually ranges from 200 to207 kN/mm². (Yu, 1985)

Ductility

Ductility is defined as ‘an extent to which a material can sustain plastic deformation without rupture.’ Cold working has the effect of reducing the ductility but this decrease will not prove to be a problem provided the minimum bend radii are in accordance with to the relevant standards. (CIPF, 1992)

Durability

In the case of cold-formed steel sections; durability primarily means the likelihood of corrosion. Cold-formed steel sections have the advantage that the steel coil can be corrosion protected under controlled factory conditions before forming. The galvanizing process will be explained in "the maintenance of the building" part.

Various profile examples used in building industry are shown in figures below. There are many other different sections may be designed and produced according to the project requirements. In building design, the most common sections are channels and Z sections. There are many variations of these basic shapes, including those with edge lips, internal stiffeners, and bends in the webs. The sections can also be joined together to form other sections with screwing gun or welding.

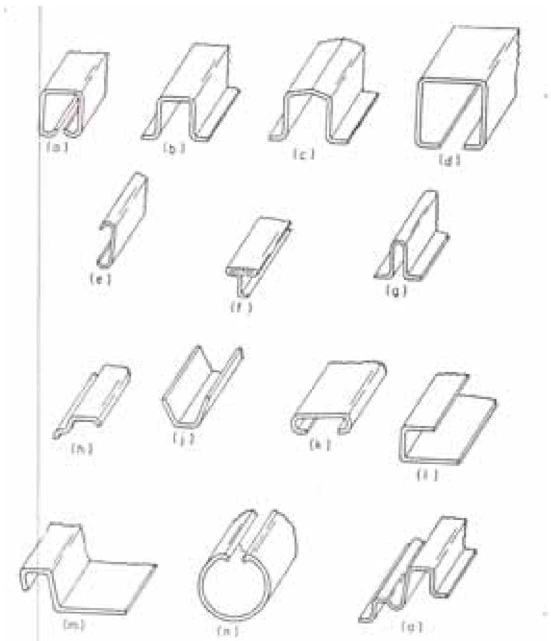

Figure B.5 Various CFS Profiles

Additional lips and stiffeners are used because no stiffened wide thin plates are able to resist significant compression and consequently the use of steel in the section becomes inefficient. However, a highly stiffened section is not easy to form and is often not practicable from the viewpoint of its connections. Therefore, a compromise between section efficiency and practicability is often necessary. (Doksatlı, 2000)

APPENDIX C

THE JOINT ELEMENTS

Welding

Arc welds are often used for factory or site joining of thin steel members. Spot welding is a technique used mainly in the factory. Fillet and groove welding can be applied both in factory and on site.

Bolts

Holes can be punched in cold-formed during forming. Bolted connections can be seen in various examples.

Self-tapping screws

Self-drilling, self-tapping screws are usually used for connecting thin steel components, for fastening sheathing to members or sheathing to sheathing at side laps. The drill part of the screw forms a hole in the steel plate. The diameter of the screws is between 4 to 8 mm.

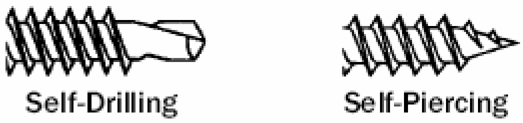

Figure C.1 Screw point type (Light Gauge Steel Engineers Association)

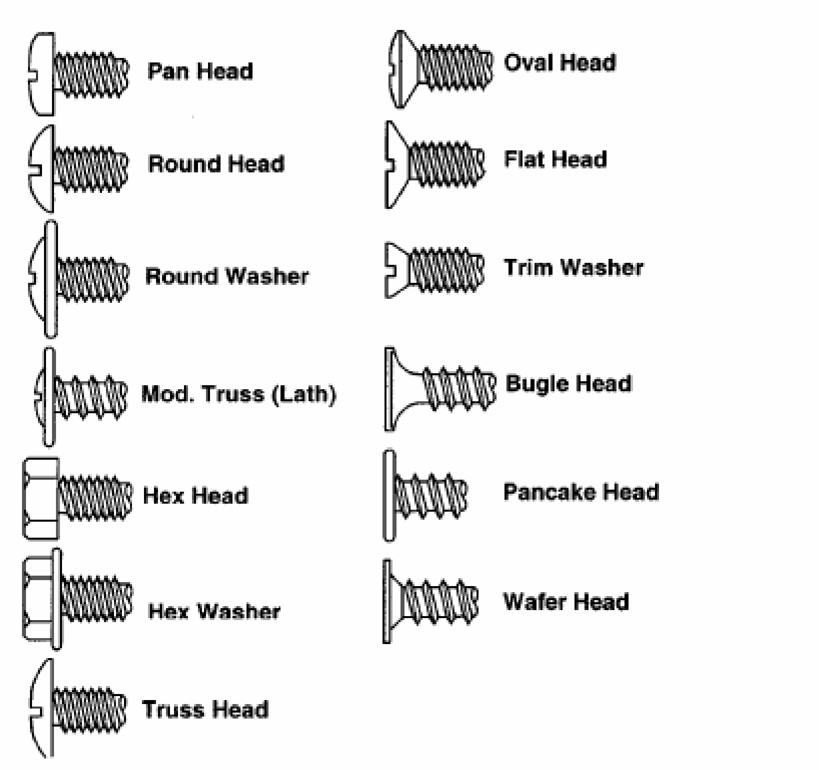

Figure C.2 Screw head types. (Light Gauge Steel Engineers Association)

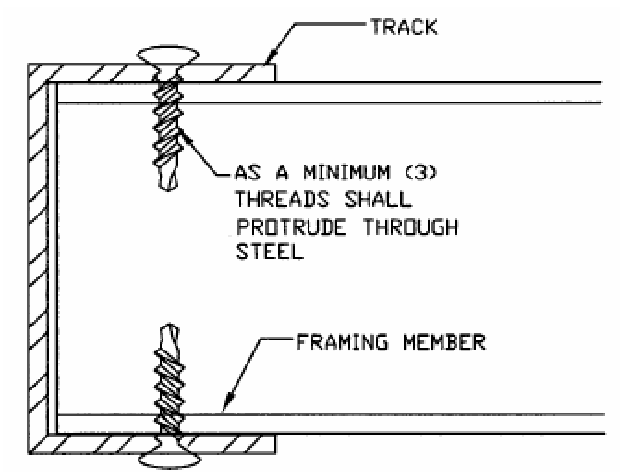

Figure C.3 Steel-Steel Connection

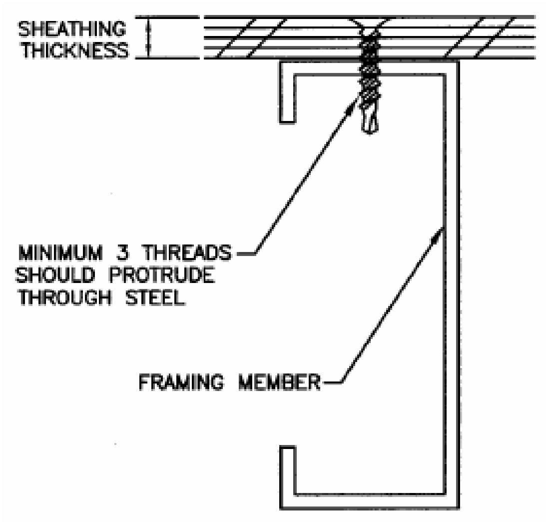

Figure C.4 Sheeting-Screw Attachment

Blind rivet

Blind rivet is a mechanical fastener capable of joining pieces together where access to the assembly is limited to one side only. They are used for thin to thin fastenings and available in several kinds of alloys. Their diameters are 2.4 to 6.3 mm.

Powder actuated pins (or shot fired pins)

Powder actuated pins (or shot fired pins) are fasteners used to connect thin to thick steel. They are usually of 4.2 mm in diameter and their powder cartridge is selected for the thickness of the steel.

Some other fastening techniques for cold-formed steel elements are plasma welding, resistance welding and adhesive bonding.

APPENDIX D

THE INSULATION ELEMENTS

“Batt Insulation: A ‘full-width’ batt shall be used for batt installation in the cavity of the framing member in order to span from framing member web to framing member web. While batt insulation may friction fit between studs, duct tape could be used to hold the insulation in place until the gypsum board is installed.

Liquid Foam Insulation: The installation of liquid foam type insulation typically requires some lateral support for the framing members due to the forces of the wet foam product expanding during its curing process. Therefore, it is recommended that the manufacturer be contacted for the installation preparation and installation instructions.

Exterior Rigid Foam Insulation: In many climates, the use of board type rigid foam insulation may be required on the exterior flanges of the studs to provide a thermal break between the steel framing and the exterior temperatures. Exterior rigid foam insulation is typically installed on steel-framed walls using any of the following:

• Self-drilling screws with washers to prevent the screws from pulling through.

• Construction adhesive applied to the studs to hold the foam in place before the siding material is applied.

• Double-sided tape applied to the studs to hold the foam until the siding is applied. Where plywood or oriented-strand-board (OSB) sheathing is used, roofing nails, screws, or adhesive may be used to attach the foam.

Suggested solutions may be found in the Thermal Design Guide For Exterior Walls [21]. For a complete energy analysis, a design professional that is familiar with thermal analysis of steel framing may be consulted. Manufacturers’ data, publications, and technical catalogs should always be consulted.” (NHBA, The Prescriptive Method for Residential Cold-Formed Steel Framing, Year 2000 Edition)