TÉCNICO LISBOA

# Extended Abstract
# Steel Modular Construction
# Case of study of a single-family house

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**Abstract:** This paper considers the different modular construction systems in modern times, as well as the differences between them regarding structural behavior. A summarized description is presented regarding modular wooden, light steel frame and galvanized steel constructions, as well as a brief reference to so-called traditional construction, resorting to reinforced concrete and masonry.
Following an internship at FCM, Construções SA and in partnership with the Modiko® company, the possibility of monitoring a work site resorting to modular construction systems was first presented. In this particular case a single-family house with a modular two-story metallic structure, including all the required preparations and works. This included observing contact with suppliers, participation in construction planning and adjudication efforts. The construction process was analyzed and described in detail, including all necessary considerations and photographic illustration, for the proper understanding of the method. Subsequently, a comparative analysis of the financial issue and divergences in construction methods is carried out, between the considered modular metallic construction and an equivalent hypothetical traditional construction. Finally, some considerations are issued regarding future development of the technology, particularly on possible approaches to further studying the topic of modular construction, deepening the understanding of these system's behavior when subjected to earthquake activity and regarding their environmental sustainability.

**Keywords:** Steel modular construction, modular construction, light steel frame construction, wood framing construction, traditional construction.

## 1. Introduction

Construction methods are constantly evolving. Nowadays building a house does not depend solely on local materials, as there are several techniques and new materials that can provide great creative freedom, allowing shapes, and within deadlines, previously impossible.

The term modular construction is used to refer to the construction technique wherein three-dimensional elements are used, independently making up the structure of the building without the need for additional support, these being produced in a factory setting for later transportation to the site of implantation. They are then assembled, linked to each other, and connected to the previously prepared foundation, forming the property. [1]

There are more and more companies specializing in modular construction, and there has been a strong growth in modular construction in recent years in Portugal. Currently still a niche market, it is a reliable and relatively accessible option for homeowners, depending of course on the builder, dimensions and chosen appearance of these homes. This type of construction already involves various types of materials, such as wood, concrete and steel.

In a very general way, this type of construction has numerous advantages such as the shorter build time, the greater control over the quality of the construction process which thus results in fewer defects, and the possibility of improvements and increases in size since it consists of individual modules, while still presenting a competitive price range.

This price may approach the values for building a conventional house, however, given the significant expenses for preparation, such as earthmoving and excavation, and the novelty of the technique.

This paper has for its main objective the monitoring of a work, namely a single family house with steel modular structure comprising two floors, as well as the comparative analysis of the financial and practical differences between these construction methods, namely the steel modular construction and so-called traditional construction.

The modular construction, besides providing economic transparency and accessibility, signals an evolution in the environment where we operate, producing innovative architectural variations. This is an adaptable construction, enabling flexible housing typology as well as flexible spaces which are important for ever faster urban development.

## 2. Modular Construction

The concept of modular construction, as it is commonly called, goes back to antiquity, evolving over time. Generally, this type of design covers any construction made via prefabricated modules, which are transported to the site of their implementation and subsequently interconnected and installed. It presents itself as a quick alternative to so-called traditional construction, however it will be important to note that the evolution of this technology makes its description, in these terms alone, inaccurate.

In addition to common modules, which are already significantly adaptable, there are also other basic structures designed for customization in detail, made of various materials such as wood, steel or concrete.
In this type of construction there is a need to pay attention to careful preparation of the land to ensure an appropriate base on which to settle foundations for the structure.

### 2.1. Wood Framing

Significant population growth was observed in the nineteenth century on the American continent, resulting in the inability of traditional building methods to meet housing needs in the market, thus making it necessary to develop a faster and cheaper system to increase productivity. The solution found at the time, called wood framing, was the use of this material as the main structural element of residential buildings as it is widely available locally.
As mentioned above, the structural material of this system is wood, applied as lightweight solid wood profiles, braced with OSB boards, which line walls and roofs (Figure 1). Structurally, this arrangement of materials allows the softening of the effects of anisotropy, that is, the variation of the mechanical behaviour depending on the direction of the applied tensions - very characteristic of this material - thus allowing to reuse discarded wood fragments.

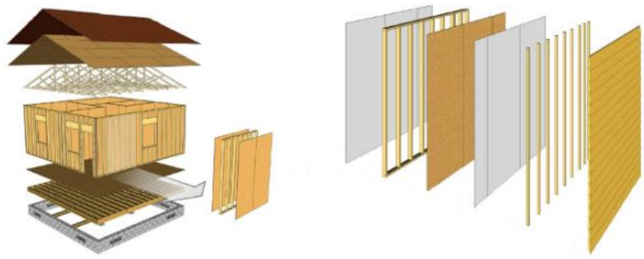

Figure 1 - Wood frame structure [2]

The speed of construction in this type of system is increased, and the walls with wood profiles can be built on the ground and raised in a single movement. Regarding thermal insulation, a process that necessarily uses materials that make heat dissipation difficult, wood presents itself as a material that is naturally poor as a thermal conductor, making the natural thermal efficiency superior in these systems. [3]
Wooden frame dwellings are designed to handle lateral forces like those produced during an earthquake. In order to control the correspondent movements, the structural elements of the roof and floors must be connected to those of the walls to the foundations, thus the importance of structural cladding, reducing the lifting forces that occur on the walls due to the lateral forces, by fixing them to foundations, combining all the elements to resist together. [4]
One of the main advantages of this construction system is the higher productivity associated with vertical siding, since OSB sheets can be produced in large dimensions. Wood is by nature a renewable material with low environmental impact, and it can be easily obtained in most places, allowing the use of smaller and less demanding technical equipment, both for transportation and assembly of parts. This type of construction generates less waste, allows for shorter construction time, and produces buildings that are durable, flexible and resilient. [3], [4] e [5]
This type of construction also has several disadvantages in its use, as it should be noted that the rough surface of OSB sheets requires greater care with finishing or and coating. The use of reinforced concrete and steel is not completely excluded from these constructions, as it is often used, for example, for floor slabs and long span beams, respectively. Another disadvantage is the need for greater care in both structure execution and design, because many elements cannot be broken or cut. The possible height of the buildings is low, and there is little supply of labour and specialized tools. [3], [4] e [5]

### 2.2. Light Steel Frame

LSF stands for the initials of the term Light Steel Frame. It is a constructive method based on the use of steel as the main structural material, made by moulding low-thickness and zinc-coated sheets by hot dip galvanizing and retaining their final shape when cold-formed by an industrial process. [6]
This generally means that the building structure, normally made of steel and concrete, is in this method entirely made of prefabricated steel elements. The profiles used, moulded in galvanized steel plate, have reduced thickness and are developed considering their future assembly via screws, forming the final structure. The structures are subsequently lined internally and externally with multiple materials of high quality and industrial production, namely OSB boards, which not only have thermal insulation functions but also serve as a basis for fixing the finishing materials of the facades; mineral wool, for instance, is placed in the space between the profiles to insulate acoustically and increase the thermal properties of the wall. The interior lining of the walls is made using plasterboard bolted directly to the steel structure, and the exterior lining can be done in the ETICS system, using EPS plates (for thermal insulation), fiberglass mesh (providing mechanical strength) and coating (protecting from seepage and promoting final finishing). The execution of the slabs and roof is done in a similar way, except that the latter must be waterproofed, with the application of a vapor barrier, thermal insulation plates and the waterproofing solution adopted in the project, such as PVC mesh, which prevents the degradation of materials by rain. [6]
It should be noted that the designation "light" refers not only here to the lightness of the material, but also to the lightness of the steel structure itself and the resulting building itself. The low weight is the result of the manufacturing process, as opposed to hot-rolled profiles which often have a greater weight.
This type of construction must take into account the particularities associated with the foundations, the construction time, the type of occupation, the site, the access points, the possibility of adaptation to other methods, the need for maintenance, the building height, durability, performance and environmental impact. [7]
There are some disadvantages to mention since the steel is cold formed, namely the susceptibility of this material to instability phenomena, the occurrence of crushing in the webs of the profiles due to concentrated loads, the existence of greater torsion deformations, and the hardening of the steel. Then there is also the high cost of this type of profile, due to the galvanization

process, which makes for complex dimensioning. [8] In addition, there are pathologies to be taken into account in this type of construction, namely: corrosion, fire effects, deformation, local or global buckling and breakage, so preventive measures need to be taken. [6]
Bolted joints are used during the manufacturing process of these LSF panels (Figure 2), ensuring greater mechanical strength and, being simple to size, are easy to install and relatively inexpensive, suitable for industrial production processes. These bonds are also used in the connection of non-structural elements to the structure itself. Some experimental studies have been performed which found that the stiffness of the panels in LSF is higher when they are coated with OSB plates instead of plasterboard, but the displacement obtained is also greater. Thus, it can be concluded that the cladding materials influence both the structural behaviour and the strength of these panels, and OSB boards are a good solution for the lateral stability of these types of structures, as well as the bolted connections used between them, with an influence on the lateral load capacity and the rigidity of the panels. [8]

Figure 2 - LSF building [7]

The structure of these steel constructions is made up of U and C type galvanized light steel profiles, calculated, designed and manufactured with strict technical control. Each frame part is manufactured to exact, pre-defined dimensions, with precise fittings and cuts pre-made for each job, eliminating material waste and increasing assembly efficiency and speed, combined with high quality control. [7]
Once completed, the final product obtained via this system results in buildings with a final appearance virtually indistinguishable from that expected in conventional construction. The main advantage lies in the full integration of modern technology, without neglecting strength or durability, in the process to achieve similar and conventional performance quickly and sustainably.

### 2.3. Steel Modular Construction

This construction system refers to parts made from zinc-coated sheet steel and subsequently undergoing a hot-dip galvanizing process, giving them ductility and strength, achieving the desired final shape through cold moulding. These types of profiles can be structurally applied to both internal walls and exterior walls, slabs and roofs. All steel elements are screwed together to give the structure flexibility.
The steel modular construction with galvanized steel profiles is very similar to the LSF construction, and the major difference is that the latter are lighter, and therefore it is not necessary to increase the robustness of the foundation on which these profiles rest, meaning that while steel modular construction allows the execution of a general lightened foundations.
Modiko® is a company operating nationwide featuring a patented modular construction system. They produce all the structural elements necessary for a steel modular construction project, from pillars, beams and walls to the fittings used in their joining. Like the systems previously described, the Modiko® construction system results from the interconnection of various prefabricated steel elements and refitted directly on site using only light lifting equipment. [8]
It is in this construction system that the work described in the next chapter was executed, in partnership with the company FCM, Construções S.A.
All the advantages listed for LSF construction are analogous to steel modular construction as well as their disadvantages.

### 2.4. Traditional Construction

So-called traditional construction refers, for the purposes of this text, to the construction of structures in reinforced concrete and masonry walls, as most commonly used in the national territory.
The roots of the use of masonry in construction go back to antiquity, and there was also an evolution in the use of materials along with alternative technologies. This type of construction continues to have multiple advantages, due to the extraordinary architectural freedom it allows, compared to the prefabricated modular structure targeted by this study. Other features to note with respect to the systems herein include the possibility of performing longer and more diverse beam spans, in addition to the possible height of construction without compromising the stability of the structure.
Concrete requires natural materials that, in general, are abundantly available in many places, but construction with this element is slower since the use of formwork, reinforcement and, as it regards concreting, needs at least 28 days to acquire adequate strength. Similarly, laying masonry also requires significant time. [6]
Reinforced concrete is a material that can deteriorate, mainly due to design or execution deficiencies, such as cracking, delamination, corrosion, disintegration, infiltration and deformation. [6]

### 2.5. Main Remarks

Steel modular construction performs significantly better than wood due to the higher quality assurance of the profiles and their connections. While these advantages are not as relevant compared to reinforced concrete structures, the strength-to-weight ratio of steel modular structures makes them an effective alternative to the much heavier conventional reinforced concrete and masonry systems.
The behaviour of reinforced concrete structures remains the prime example of safety for both seismic activity and other structural stresses. If good engineering principles and appropriate construction methods are applied, a masonry building can and should prove to be very effective in resisting seismic forces. However, it appears

that the LSF construction system achieves a similar behaviour while introducing less mass, less labour, reduced means of transport and lifting and, consequently, with more competitive prices or terms. In addition, in most cases of rehabilitation of older buildings, the advantages of the steel modular system often make it one of the few possible alternatives for space subdivision, floor addition or roof remodelling. In addition, it is attractive for allowing, outside the needs and requirements of safety and functionality, to obtain comfortable living and working conditions easily. Thus, obtaining buildings that are both safe and comfortable, as would be ideal, can be facilitated using structural systems in steel modular structures.
Purchasing private housing is, in most cases, the largest investment the average citizen will make in a lifetime. As a result, any structural problems and other drawbacks during the life cycle of a habitable structure can be both financially and emotionally draining.
As a result, one of the main advantages that should be retained by the steel modular system is the democratization and simplification of the satisfaction of safety requirements for private housing, including the action of natural disasters such as seismic activity, with guarantees of quality and consistency. even at short notice. In Portugal, given the predisposition to seismic activity, this feature becomes particularly relevant.

## 3. Case Study

The case study deals with a single-family house in Alhandra, Vila Franca de Xira, typology T2, with no conditions to report that interfere with the construction of the unit centered on the plot. This was under development, resulting from a partnership between the companies FCM - Construções SA and Modiko® - Modular Construction Technology, through a modular construction system whose main advantages are the ease and speed of execution, profitability and versatility of the solution when compared to so-called traditional construction methods.
The design of the structure in question was adapted from LSF construction to steel modular construction, reflecting this fact in the alteration of the initially planned foundation arrangement (foundation footing and beams) for general shallow foundation slab resorting to cement blocks.
Given the steep slope of the ground, the central deployment of housing on the plot involved significant volumes of land movement.
The design solution foreseen in the project is characterized by the general steel structure, consisting of hot dip galvanized profiled elements, seated under a collaborating slab. There are steel sheet outer panels, attached to the structure and covered with a bonnet. The roofing is flat and non-accessible, consisting of a layer of heat-sealed PVC mesh, applied over an EPS insulation layer and collaborating plate. Inside, the walls are made of painted plasterboard, including rock wool.
Some of these features have been partially changed throughout the work, as will be discussed later in this chapter. The originally planned deadline for implementation was agreed at 12 months.

### 3.1. In situ works description

#### 3.1.1. Site Preparation

Based on the topographic survey, the ground was prepared (Figure 3), including clearing and earthmoving actions in order to obtain the rock mass layer for subsequent implementation of the structure. The compaction and levelling of the ground were conditioned to respect the threshold level required by the Vila Franca de Xira City Council.
After the preparation of the ground, the lateral formwork of the ground floor was carried out according to the drawing of the assembly scheme. Next, the sealing screen, in turn, is composed of an overlay of two layers of 250 g/m² geotextile blanket, including layers of plastic sleeve and 30 mm XPS thermal insulation. It is on this canvas that a 100 mm thick surface of cleaning concrete C12/15 S3 X0 (P) D16 Cl 1.0 is executed (Figure 4), on which the remaining structure was laid.


Figure 3 - Site preparation


Figure 4 - Cleaning concrete

#### 3.1.2. Assembly of Porticated Floor Structure

The assembly of the Modiko® structure then begins with the initial attachment of the steel footing plates to the cleaning concrete (Figure 5). The correct alignment of these (Figure 6), using pre-levelling and project implementation data, aims to ensure that their axes later coincide with the axes of the pillars of the structure. Clamping is done via M10 segmented bushings.


Figure 5 – Steel footing plate fixed to cleaning concrete


Figure 6 - Steel footing plate alignment

This is followed by the assembly of Modiko® galvanized steel profiles, whose operation is analogous to that of columns, which are bolted to the corresponding bases (Figure 7). These profiles, a fundamental element of the construction system used, originate from galvanized steel sheets of class S275 JR+M, according to EN 10025-2, having configuration in “C” (Figure 8), 3 mm thickness and longitudinal drilling for M12 screws in the flanges and in the core, the latter with additional holes of Φ27. This profile shape is closed at the ends by two “L” shaped tops, allowing the top fittings between profiles on which the entire mounting system rests.

Figure 7 - Steel footing plate bolted to the pillar

Figure 8 - Modiko profile “C” [14]

This profile, combined with union pipes, allows for additional configurations, called “2C”, “3C” or “4C”, depending on the number of “C” profiles joined. The “2C” configuration is often used either horizontally, as a beam, or vertically, as a pillar. It can be of varying standard lengths and, using connection brackets, it is also possible to connect flanges between profiles for different dimensions. The general solution obtained by the fitting of the elements is a ported structure, joined exclusively by bolted connections.
The “3C” profiles, consisting of the joining between the “2C” and “C” profiles, are obtained by means of a special joint, in the form of a “U” rail, which has been previously assembled. Coupling the pillars to the upper plates of the respective shoes, and then securing, via threaded rods, also to the lower plate (solidified with the cleaning concrete) (Figure 9).

Figure 9 - Pillar mounting

Figure 10 - Mounting of Perflex profiles

Figure 11 - Mounting of wall profiles

Following the installation of the abutments, Perflex profiles were installed (Figure 10), similar in configuration to the remaining MODIKO “C” profiles except for the absence of tops. For the purpose of the modular construction process, the Perflex profiles perform the function of secondary structure, used in the fixing of wall and pad panels or as ceiling and floor beams, on which roofing sheets are based (which may be used here), marine plywood or corrugated sheets, as desired.
Said wall profiles were then assembled (Figure 11), using connection brackets placed on the tops of them in order to better support them with the core of the M12x25 pillars. There is no need for verification of dimensions since they include factory pre-drilling. Three approximately equidistant Perflex profiles are applied, the first being placed at the level of the foundation concrete and the others respecting the distances provided for in the mounting scheme. In this process the reinforcements of the “C” section are oriented to the exterior of the house.

To these are added the profiles for fixing to the frames, as well as those on the periphery of the roof, which will have the function of installing and supporting the façade panels, operating in a similar way to a platform, by screwing in the profile “C” to the exterior of the roof beam. A pair of 290 mm billets is added to these profiles to promote the joining of the joists of the profile beam and Perflex profile. Finally, “L” fixing rails will be installed which will be used, as the name implies, in fixing the façade panels to the rest of the structure by means of M12 nut bolts, which are also pre-drilled.

Figure 12 - Fixing profiles of frames

Figure 13 - Installation of the fixing "L" rails

After assembling the Perflex profiles, the beams were mounted on top of the pillars. Firstly beams are applied whose direction allows them to rest directly on the pillars (main or principal direction) and later beams are added placed to their perpendicular direction (secondary direction) with direct attachment to the main direction beams. This connection is made using M12x25 screws and, when continuity is desired on a main beam, the tops of the beam are bolted simultaneously to the pillar and the adjacent beam. In the case of secondary direction beams, in order to maximize the contact area between profiles and to reduce the puncturing to which the bolts are subjected, U-fittings are employed.

Figure 14 - Mounting the beams

Figure 15 - Detail of the "U" fittings employed.

The next process was the assembly of diagonals. Ceiling diagonals are installed in multiple corners of the modules and are bolted directly to the lower profile flange, fulfilling locking functions, as well as wall diagonals, which are placed between outer pillars, whose attachment depends on diagonal fittings bolted to the posts and anchor hooks that will be bolted to the concrete surface.

Figure 16 - Installation of ceiling diagonals

Figure 17 - Installation of wall diagonals

Finally, the closing of the frame is performed with locking boxes applied over the tops of the frame towards the main beams. These are available in two different sizes, 150 and 300 mm, for closing “2C and “4C” beams, respectively, using M12x25 screws, except in the transverse direction where bolts are used (M12x45).

Figure 18 - Grounded floor structure

### 3.1.3. Mounting of facade panels

The facade panels included walls, patios and terraces, which also have standard measures. They are modular elements obtained by joining a metallised P11-100-12 cold rolled steel profiled sheet of class S250 DG+Z and a self-extinguishing (fire rated) EPS thermal insulation plate E) 120 mm thick class 200 using a single-component polyurethane adhesive (ADESAN CPS-B). The width of these elements can take values of 525 and 1050mm, forcing the structural perimeter of the housing to assume a multiple value of these. Regarding the height of the panels, they have their own configurations for the ground floor walls, high floors, terraces and paddles, the latter varying according to the need for blinders in the outer space.
Any of these panels are delivered partially finished to the factory site with notches on all faces for mounting by simple juxtaposition, laterally or in height, with numerical identification. The panels have a first coat of mortar for gluing and cladding, as well as a 160 g/m$^2$ cappoto-type finishing with fiberglass mesh over its entire surface.

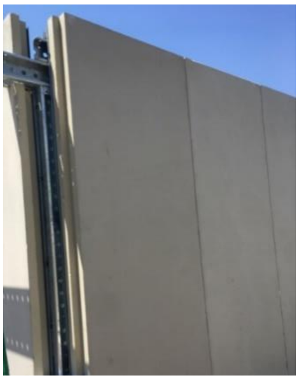

Figure 19 - Detail of the notches in the facade panels

Figure 20 - Detail of the numbering of the facade panels

The panels are placed in accordance with their numbering and relevant design and are fixed to “L” rails with self-drilling screws. After placing all the facade panels, corner closures of the pillars and jambs are completed with the placement of EPS pieces and non-expanding polyurethane foam to mitigate thermal stresses at these points.

Figure 21 - Detail of jamb closure

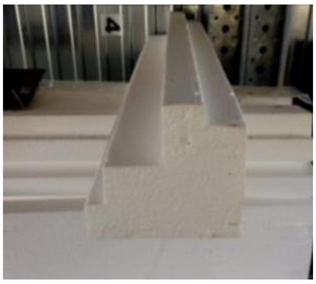

Figure 22 - EPS fastener detail

The ETICS system was then completed with the application of finishing and smoothing, comprised of Weber Therm Pro, and placement of the fiberglass mesh in joints, corner profiles and drip panes. The surface was subsequently coated with thin reinforced plaster, the cappoto system, in order to mitigate the cracks in these most critical areas.

Figure 23 - Detail of fiberglass mesh angles

Figure 24 - Detail of fiberglass mesh in joints

Figure 25 - ETICS system

### 3.1.4. Execution of floor slabs

In this phase, the A500NR steel ground floor slab reinforcement was performed, opting for a lightened solution in cement blocks (750x250x300 mm fungiblock) and #AQ50 steel mesh, while taking the opportunity for laying the necessary piping for the infrastructure networks such as water, sewage, sleeves and ITED, which are intended to be embedded in the concrete. Once this process is completed, the slab (C20/25 S3 XC1 (P) D16 Cl0.4) is concreted with the aid of a pump up to the defined design height. Subsequently a 70mm layer of fiberglass mesh screed is applied.

Figure 26 - Mounting the ground floor steel reinforcement

Figure 27 - Detail of the ground floor concreting

For the execution of the first-floor slab, it will first be necessary to place Perflex profiles supporting it and the roof. These were installed according to the orientation of the secondary beams, given the small spans of the house, providing enough strength for support and using M12x30 screws.

Figure 28 - Mounting the Supporting Perflex Profiles

Figure 29 - Assembly of marine plywood boards

To this effect, the slab is made of 24 mm thick marine plywood slabs that will form the remaining floor materials. These plates are fixed directly to the Perflex profiles with 6.3x50 mm self-drilling screws, and a flexible 10 mm cross-linked polyethylene (impactodan) blade is superimposed for soundproofing. It is directly on this insulation that the screed layer is installed, provided with a fiberglass mesh, on which the desired final coating will be laid.
In this phase, the 30 mm thick softwood limestone and masonry stones were also placed.
The execution of the structure of the first floor is analogous to that of the ground floor.

Figure 30 - Screed layer of the 1st floor

Figure 31 - Stonework

### 3.1.5. Roof Execution

On the ceiling beams P9-111-25 collaborating plates were placed, fixed to the Perflex profiles with self-drilling screws, in preparation for the execution of the remaining structural cover. This consists of a vapor barrier, on which 60 mm thick XPS plates and EPS plates of different thicknesses form the roof's pendant. After the placement of the latter, the roof was finished with water and air conditioning outlets.

Figure 32 - Placement of collaborating plates

Figure 33 - Placement of XPS and EPS plates

Finally, the 1.5 mm-thick Danopol-type PVC mesh was placed, screwed and fixed to the EPS plates and collaborating plates, hot-welded so that no discontinuities remained. The platband end was also executed using a collared plate resting on it.

Figure 34 - PVC Screen Finishing

### 3.1.6. Execution of interior walls and suspended ceilings

It is at this stage that the perimeter interior walls and the interior partition walls are assembled, formed by steel strips and mullions spaced from 600 to 600 mm, high density mineral wool and 15 mm plasterboard, except in damp areas such as kitchens and toilets where the mullions are spaced from 400 to 400 mm and the gypsum plasterboard boards are the same thickness.

Figure 35 - Execution of the perimeter interior walls

Figure 36 - Execution of interior partition walls

Figure 37 - Execution of the interior walls in plasterboard

Figure 38 - Design of interior walls in waterproof plasterboard

In some areas, in particular where suspended furniture or television stands were intended to be used, among other accessories, 30 mm-thick marine plywood reinforcements were placed, bolted to the mullions, due to the low strength of the plasterboard.

Figure 39 - Detail of marine plywood reinforcement and insulation placement

Figure 40 - Beginning of the interior partition wall busbar

After completion of the walls, a general busbar is executed and the walls of wet areas are waterproofed with one-component mortar to ensure that the plasterboard is not exposed to moisture or gets in direct contact with running water.
Afterwards, the entire structure of the suspended ceilings, supported by hooks fixed to the ceiling beams, also filled with high density mineral wool, was executed, but in this case the plasterboard plates are 13 mm thick. The ceilings were completed analogously to the construction process employed for walls.

### 3.1.7. Final Finishes

It was at this stage that the low-emissivity double-glazed PVC window frames were placed. The gaps used are fixed to the abutments and in some cases special parts are required to compensate for the distance between the core and the “C” profile flanges as well as 25 mm compensating rims placed in all the spans, to facilitate the interior finishing of the plasterboard with the frames and the finishing of the wooden baseboard. The pieces were placed on the outside face of the pillars, according to the step of the frame drilling, to eliminate thermal bridges. As a protection system from sun exposure, blackout screens are used indoors and monoblock blinds of rulers and shading on steel fins are employed outside.

Figure 41 - Special parts for frame fitting

Figure 42 - Python screen along the perimeter of the house

Still in this phase the wall and floor finishes are applied, namely ceramic mosaic and floating stratified floor, the paintwork is executed with white paint on plasterboard boards, as well as carpentry and access stairs to the upper floor. In the steel structure, with painted finish and wooden steps, glass guards are also applied in their respective spans and, finally, the sanitary accessories and other equipment are installed.

## 4. Case Study

### 4.1. Results of single-family home under study

Initially, a quantity map was supplied by Modiko® and a verification of the measurements was made.
For reinforced concrete, a measurement was made of all areas where geotextile blanket and plastic sleeve would be applied, as well as 30 mm XPS thermal insulation, including accounting for the necessary cuts, particularly across the ground floor, inaccessible balconies and roofing.
For the concrete and fiber cement block surface, the amount of steel required as well as the amount of concrete was measured based on an Excel document owned by the builder in order to fill the entire ground floor.
Concerning the levelling screed, it was measured based on the sum of the areas of the whole ground floor and the first floor.
The chapter regarding the quantities for the modular structure has not changed since it concerns a fixed price defined by Modiko® which includes the supply of modular galvanized steel profiles for the execution of the framed structure and modular wall panels.
For insulation, all areas covering façade panels for the application of reinforced thin plaster had to be measured.

Namely, the busbar area of the entire outer surface of the panels, while considering the corner, drip pan and plate joining profiles. Finally, the primer application for the final coating and the final finish itself was also calculated.
The entire roof area and inaccessible balconies were calculated to account for the dimensions of waterproofing membrane needed to cover the entire area, including sheet steel profiles in the transitions between the horizontal plane and the vertical plane.
It was at this stage that the rainwater drainage pipes were accounted for via the water and sewage project.
To measure the walls and ceilings in plasterboard, in addition to accounting for the areas of wall in normal and waterproof plasterboard, it was necessary to account for all other accessories, such as strips and mounts, screws, insulation bands, paper strips, mineral wool and bushing, which are necessary for their execution. The process is analogous to the accounting of plasterboard ceilings, normal and waterproof, except instead of strips and mullions we have ceiling and pivot profiles, and instead of insulation bands we have splices, while adding threaded rods, corner profiles and lacquered fins.
At this stage one can still consider the total area of walls and interior ceilings for painting.
In this phase the areas of the house that were to be filled with floating stratified pavement, as well as with ceramic mosaic were measured. The procedure for accounting for the areas where ceramic tiles would be placed on the walls is like the previous one.
Finally, all swing doors and sliding doors with cassette, as well as the door jambs and fitted wardrobes with the existing architectural design are considered. All baseboard locations were measured. Sanitary facilities were also accounted for, including all hardware and connection fittings.
For the supply of PVC window frames the gaps in the house were accounted for, as well as their measurements, which were later confirmed on site.
For the execution of the infrastructures, these were executed according to the project and in response to the indicated quantities, including the necessary material and equipment.
After all the confirmatory measurements of the quantity map of all the work were done for the housing, as well as the survey of all the materials necessary for the execution of the work, the entire project was planned, subcontractors were surveyed and suppliers contacted in order to request prices, delivery times (in the case of materials) and payment methods for the execution of the contract.

### 4.2. Comparative Analysis

In order to make a comparative analysis, it should be borne in mind that some of the construction methods used in the execution of single-family housing in steel modular structure have similarities with the alternative reinforced concrete structure, and these are not portrayed in this subchapter. Here, a comparative analysis will be made only between the construction methods that distinguish the two building systems, as well as their financial evaluation and comparison of deadlines for each of the different structures.
The single-family house consists of a total construction area between ground floor and first floor of approximately 15 m$^2$.
The main difference will be between the steel modular structure, which is executed using prefabricated profiles with equivalent functions to beams and columns, while in the so-called traditional construction, they will be made of reinforced concrete. The footings are also made analogously to the remaining structural elements.

### 4.3. Main Remarks

Given the obtained figures, modular construction translates into approximately € 123 000 for the work in question, while reinforced concrete construction has a lower value of approximately € 89 000. It can be noted that this difference is mainly due to work on the steel modular structure, although the value obtained for the reinforced concrete including the footing shallow foundations.

## 5. Conclusions and future developments

### 5.1. Conclusion Remarks

It is important to note that the relatively recent emergence of steel modular construction in the market, particularly in Portugal, translates into a significant absence of competition for companies in this segment of construction solutions. Thus, it will not be reasonable to assume that the current monetary values involved will continue after price stabilization given the increasing adoption of this technology, with the expected approximation of the respective budget values to the so-called traditional construction in the future. Currently, however, the unique advantages of the solution and the scarcity of availability of suppliers operating in Portugal leads to higher prices.
Most of these advantages derive from the higher quality control achieved by prefabricating the material under industrialized conditions, which allow for guarantees of accuracy that are difficult to reproduce with the on-site execution of works via traditional construction. For the final customer, particularly in the case of works such as that set forth in this document - a single family home - for which no technical knowledge will be expected from the developer, the accuracy mentioned above translates into increased confidence in product quality.
Finally, the advantage obtained in terms of deadlines and timing for the work is difficult to ignore. For work performed through conventional methods which could be expected to last up to one and a half years, execution with modular prefabricated solutions allows the completion of an equivalent product between four and six months, effectively reducing the time by more than half. Although the novelty of the solution may add to the apparent final cost, the execution of equivalent housing under traditional construction within the time allowed by modular construction would result in a much more significant increase of the cost. On equal terms, given the same time frame and quality, the modular system has obvious economic and schedule advantages (Figure 43).
The use of systems such as Light Steel Framing offers multiple real advantages over wood or masonry structures. Buildings are designed to withstand the stresses resulting from seismic activity by absorbing the energy transmitted to them by ground movement in the event of an earthquake. In this sense, flexibility gains in the structure allow a greater adaptation to the ground's movement, depending on the overall behaviour of the

materials applied, the structure's configuration, the construction quality, the design calculations and the correct application of appropriate legislation.
Wooden frame or light galvanized steel frame housing is designed according to concepts similar to other engineering works. In order to deal with lateral forces such as those produced during an earthquake, the structure being subject to sliding with sudden changing movements, the importance of guaranteeing the monolithism of the structure, by solidifying the structural elements of the roof, stands out. Wall deformation shall be limited to tolerable levels and all roofs, floors and walls shall be calculated with a view to limiting movement and shifting loads to walls resistant to horizontal actions to ensure the stability of the building.

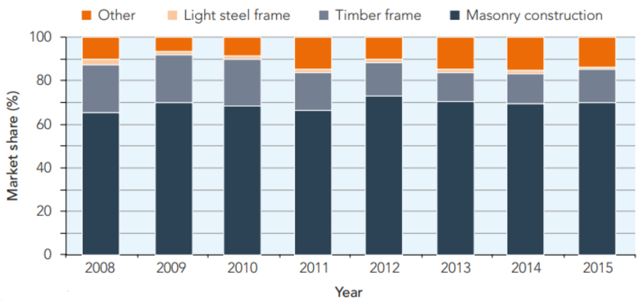


Figure 43 - Construction type statistics on the market between 2008 and 2015 [12]

### 5.2. Future Works

One of the studies that can be developed in the future is the sustainability of this type of construction, as well as the fire resistance and its performance against seismic activity. Additional consequences of incidental disasters, such as tsunamis and fires caused by infrastructural damage, often result in significant economic and social losses with a risk to the physical integrity of residents in exposed populated areas. [10]
The production of steel structures has been significantly increased and, in this case, it would prove important to develop recycling and waste disposal schemes, improving environmental sustainability.

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