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A Comparison with Light Steel Frame Constructional Building Systems for Housing

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Abstract: Cold-formed profiles were first used together with the partition elements of the inner space and with roof systems (rafter etc.) due to their light weight. Approximately 1000 residences were built in 1992 in USA by means of light steel systems made of these profiles; whereas, this figure exceeds 30.000 residences today. In addition to USA, this system is commonly used in Japan, Canada, Australia and Europe. This system is preferred mainly due to its light structure, easy production opportunities, fast assembly, as well as clean construction site conditions not leaving any waste. Light steel structure systems being compatible with flexible planning thanks to its basic design principles are appropriate for earthquake regions and low-income families with its easy and cheap production costs. This study classifies light steel systems as stick, panel and box systems and highlights numerous of plan and facades when designed with respect to the modular design principle and generation of many alternatives on the basis of plan schemes consisting of 2 modules and combination estimations based on 3 flats.In this paper light steel frame constructional building systems design in residential housing are examined from the beginning of design stage to using stage by production methods as stick, panel and box system. And examined also façade design, plan alternatives and sub systems design.

Key words: Flexible design · Light steel frame · Residential housing

INTRODUCTION

Traditional building materials and methods are hardly suitable for systematization and prefabrication of housing components. In other building areas steel has had the exclusive rights for decades [1, 2].

Steel is obtained by means of carbon rating to 0.5-1.5% of iron and manganese alloy rating to 0.5% of iron. Structure elements used for light steel construction systems are made by means of cold forming of hot-rolled roll galvanized sheets made through hot-dip galvanize technology. Thickness of profiles differs between 0.50 mm and 2.50 mm with respect to the static estimations and their usage places [3, 4]. Basis of light steel structures is mainly made of reinforced concrete. Foundation wall, footing and sub-basement girder are all constructed with respect to the foundation structure and structure loads. Less dead load of the structure in comparison with other systems provides lighter and smaller foundations for light steel structures. In some cases, footing may not be required depending on the base structure. Foundations also vary in accordance with whether pedestal and basement is to be constructed or not [5].

Flooring construction principles of light steel structures present various common and different properties at ground floor and mezzanine. Having minimum web width of 185 mm and wall thickness of 1.1 mm, C or Σ profile floor beams are created with a space of maximum 610 mm. If joists are dimensioned properly, an opening of about 6.5 m may be exceeded. Joists should be stabilized against horizontal loads by means of brace or division bars. Flooring of the ground floor is anchored to the foundations with an interval of 80 cm. Dimensioning and arrangement of joists at the mezzanine is same as flooring joists of ground floor. Joists should be at the same axis with the posts. It is important to provide rigid structure against horizontal loads during establishment of vertical bearing and curtain wall and not to loss rigid structure during arrangement of spaces. Load bearing walls are created by means of rigid connection of profile

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C posts having minimum web width of 90 mm with lower and upper headers as to have maximum spacing of 610 mm [6, 7]. In cases where post height is up to 240 cm, walls may be made rigid as to insert sash bars in the middle. If the length of posts is more than 240 cm, walls may be made rigid by means of sash bars or cinctures in which case walls shall be one third of posts [8, 9]. Cinctures whose width is equal to at least flanges of posts (minimum 38 mm in width and 0.835 in thickness) should continue through the wall. Steel profiles placed across the wall, flooring and roof system with a space of 40-60 cm should be connected with intermediate elements horizontally. Walls should be reinforced externally by means of cross tie members called also as wind transverse. Light steel elements may be connected to each other by means of screw, bolt, rivet or welding [10, 11].

Space should be left between flooring and ceiling coverings in order for horizontal circulation of services required. However, attention should be paid to prevent any contact between pipes, cables and bearing system. While installation elements are arranged in parallel direction to the flooring beams, spaces left between the beams may be used easily. These installation elements are hanged to the light steel beams by means of connection elements. These elements should provide required insulation. It is possible to deliver electrical installation within wall construction in the case of light steel structures having high prefabrication.

The building system characteristics would be summarized as follows: [12-14].

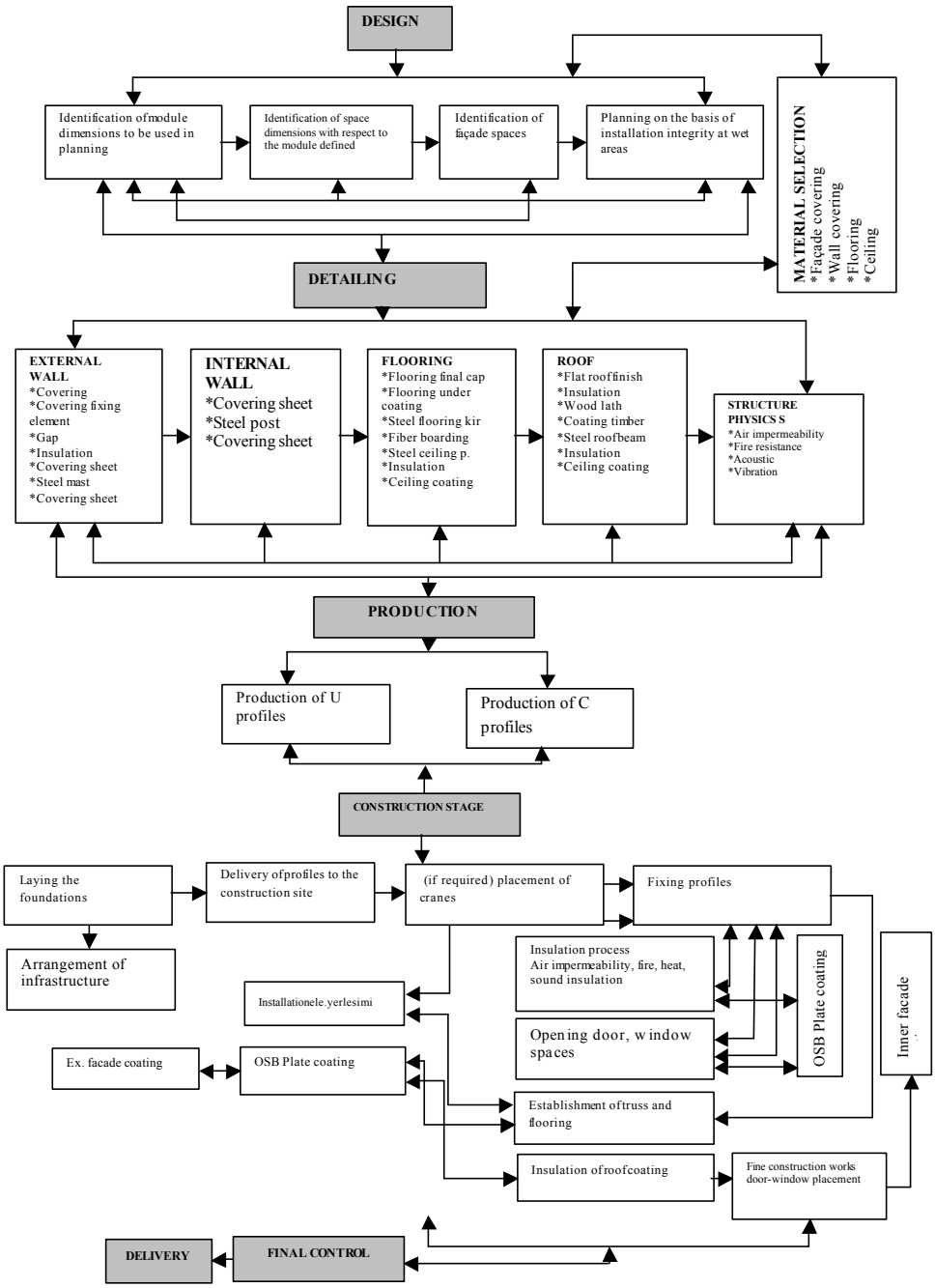
- The light construction residential house's frame is assembled from cold formed steel profiles. In the gaps between the elements of the frame heat insulation material is placed and the frame is supplied with surface layers made of various materials, forming a layered structure.
- Generally, the elements of the frame structure are constructed of C and U profiles with a dry, assembly style building technology. Numerous steel fasteners, stiffeners and other complementary profiles are connected to the basic elements of the structure.
- The applied materials filling the gaps between the elements of the frame not only perform heat insulation, but also meet acoustical requirements and they are an efficient fire protection tool. With the application of efficient heat insulation materials a good level of fire protection and an excellent heat and sound insulation can be achieved.
- The inside cover is mostly made by plasterboard. Composite layers by wood as basic material (e.g. OSB) are preferably used as outside wall board cover and floor slabs. With this, we can exploit the advantage of high strength, which provides stiffening function.
- Steel construction components can be pre-measured and precut to exact specifications. On-site adjustments are generally not required.
- Steel components generate minimal waste and all light-gauge steel construction materials are 100% recyclable.
- Horizontal and vertical dimensions of space or structure elements, as well as coordination dimensions are selected among multiples of a specific dimensional module during design of the structure. This is named as "standard basic module" and indicated with the symbol M having a size of 10 cm. However, sub-modules such as M/2 or M/5 may also be used during identification of dimensions of elements like wall, flooring, etc. 3M upper module and its multiples are used for larger structure elements. The objective is to provide much more decrease in dimensional diversity reduced through M module through limitation by 3M module. Multiple modules may be obtained by repetition of 3M basic module, such as 3M, 6M, 12M, 15M, 30M...
- The distance between light steel posts constituting the load-bearing walls cannot be larger than 610 mm. In addition, flooring beams should be on the axle of wall masts.

MATERIALS AND METHODS

Light Gauge Steel Assembly Method: The three basic light-gauge steel assembly methods are stick-built construction, panelized systems and pre-engineered systems. The American Iron and Steel Institute (1994) best describes these three methods as follows:

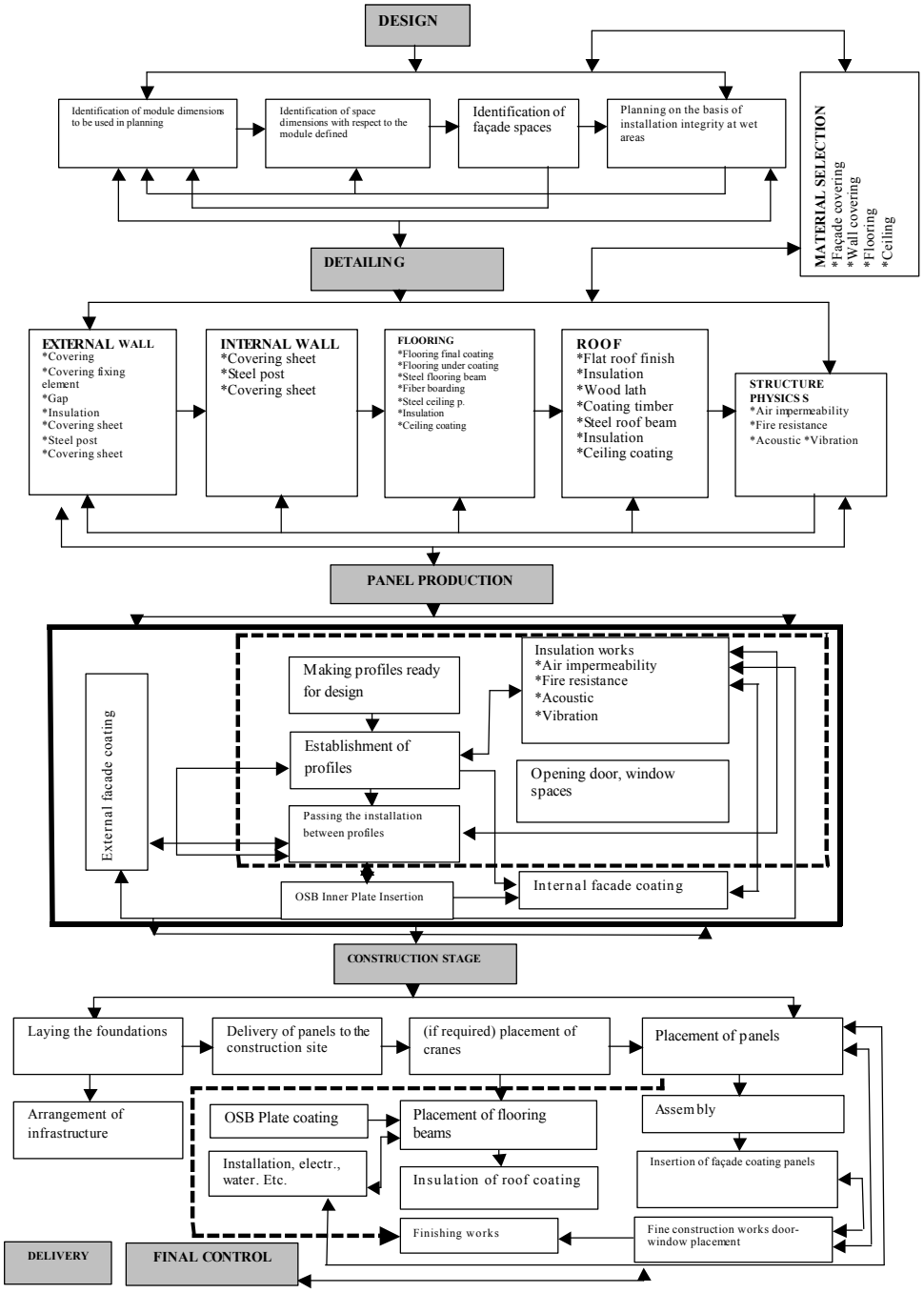
Stick-Built Construction: Stick-built construction is virtually the same in wood and steel. This framing method has actually gone through a transformation incorporating many of the techniques used in panelized construction. The steel materials are delivered to the job-site in stock lengths or in some cases cut to length. The layout and assembly of steel framing is the same as for lumber, except components are screwed together rather than nailed. Steel joists can be ordered in long lengths to span the full width of the home. This expedites the framing process and

Table 1: Stick System



eliminates lap joints. Sheathing and finish materials are fastened with screws or pneumatic pins [15, 16]. "Stick framing" is the method most commonly used to build light steel framed homes today and involves assembling the floors and walls using individual studs and joists on the construction site. This method often requires extensive cutting of individual framing members and requires a fairly high level of skill of framers who must know how to assemble the elements within the house. Framing and trusses represent approximately 20% of the total cost of the house construction [17, 18]. Table 1 presents construction stages of bar system. Profiles cut through pre-production are gathered during their production place. Therefore, work flow of production stage indicated in Table 1 is much more intense than other sections. As the production with bar system is based on construction site, construction stage is considered as much more intense when compared to the production stage.

Table 2: Panel System



Panelized Systems: Panelization consists of a system for pre-fabricating walls, floors and/or roof components into sections. This method of construction is most efficient where there is a repetition of panel types and dimensions. Panels can be made in the shop or in the field. A jig is developed for each type of panel. Steel studs and joists are ordered cut-to-length for most panel work, placed into the jig and fastened either by screws or welding. The exterior sheathing, or in some cases, the complete exterior finish, is applied to the panel prior to erection. Shop panelization can offer several significant advantages to the builder [18-20]. Due to light weight of panels, they can be delivered and mounted easily by 1 or 2 workers. Load-bearing system of any residence having 2-storey standard dimensions can be completed within 1 or 2 days by 5-6 persons. The panel shop provides a controlled environment where work can proceed regardless of weather conditions. Application of sheathing and finish

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, most often the cost advantages of panelization offset the added transportation costs. A major benefit of panelization is the speed of erection. A job can usually be framed in about one quarter of the time required to stick-build. When you consider that the exterior finish system may also be part of the panel, the overall time saving may be even greater [17, 18, 21]. As for load-bearing systems consisting of separate panels, attached structure of these panels should endure earthquake.

Flow chart of production stages of panel systems is shown in Table 2. Panels are completed within factory environment and delivered to the construction site. Therefore, their related works are mitigated within construction site when compared to the bar systems.

Construction stage of panel system takes longer times when compared to the bar system and production of other sub-systems is implemented at the construction site. Due to size of panels, human force may not be enough to mount these elements; therefore, crane may be required.

Modular System: Modular construction comprises prefabricated room-sized volumetric units that are normally fully fitted out in manufacture and are installed on site as load-bearing 'building blocks'. Their primary advantages are [22].

- Economy of scale in manufacturing of multiple repeated units
- Speed of installation on site
- Improved quality and accuracy in manufacture.

Time on site depends on the amount of factory produced components and those that are assembled traditionally.Buildings may be constructed from large and small components delivered to site and fabricated by many different trades. Build times are compromised by material and skill shortages and by inclement weather. Buildings that are 100% manufactured in a factory, possibly many hundreds of miles from the site, delivered by road transport and erected on site by crane using skilled assemblers are not subject to these on-site problems.

Modular system provides the opportunity to construct 10-storey structures by means of special heat insulation system arranged to increase fire resistance and additional steel connection elements. Modules may be gathered together through overlapped masonry structure principle or placed within carcass system. Dimension of the system is 3x12m with respect to the bearing truck dimensions [23, 24]. Modular box housing system refers to houses that are constructed in remote areas and are later collected at the required place. The cranes are put to the different modules to a particular place to construct a single building for residential purposes [25].

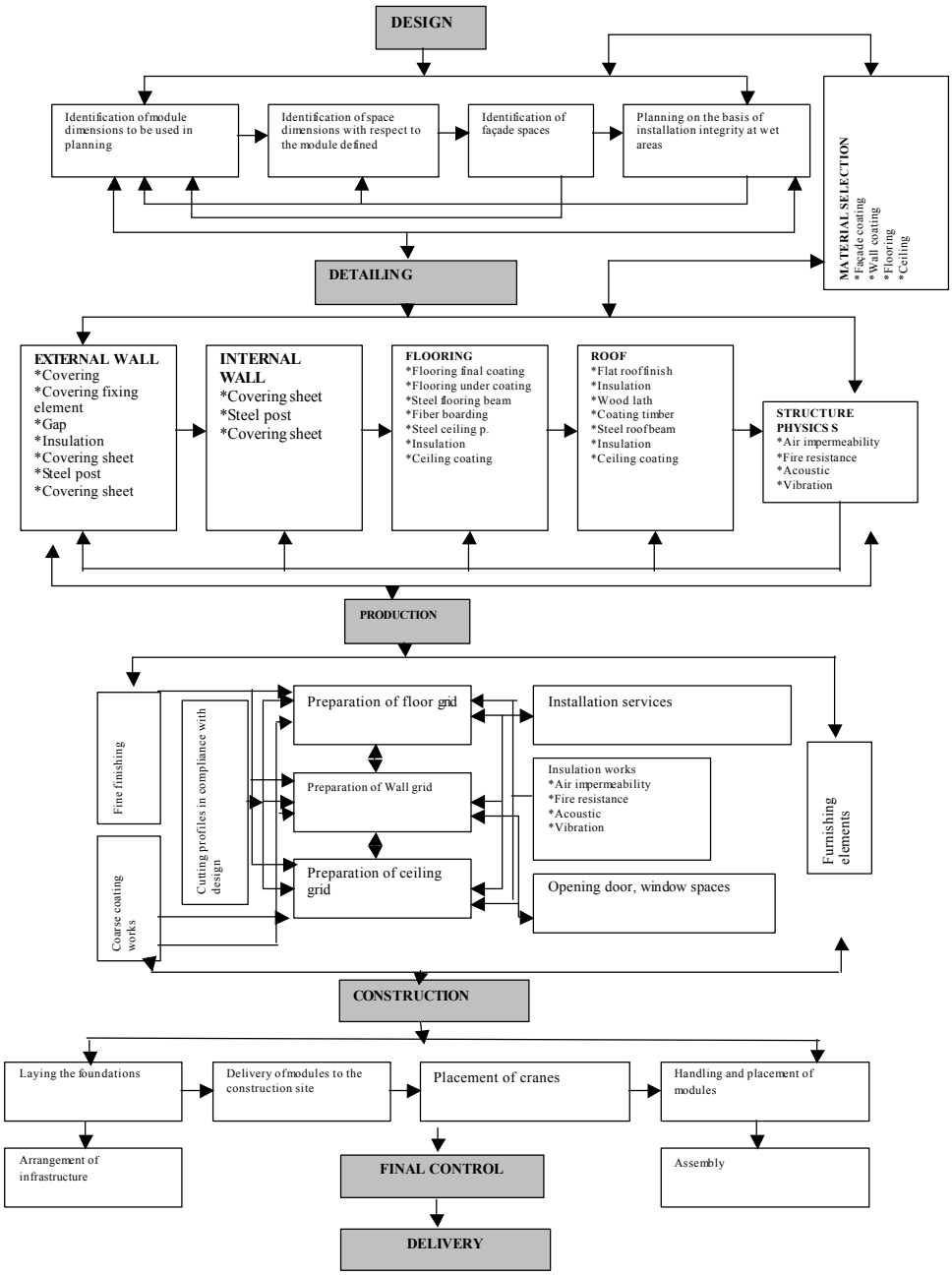
Table 3 indicates production stages of modular system. As modular systems are completely finished products, they provide high rate of workmanship and time saving when compared to other systems.

Light Steel Construction System of Residences Being Compatible with Modular Design

Alternative Modules Plan Applications at Light Steel Structures: Due to small openings of light steel systems and existence of load-bearing walls in the scope of the system, planning alternatives are restricted. Generally, it is preferred that load-bearing walls should follow each other and should be arranged in close rates as of both sides. Therefore, square and rectangle structure forms are preferred [9, 26-28, 30, 31]. Contrary to the load-bearing and curtain walls, partition walls do not bear the task of carrying vertical and horizontal loads. Accordingly, they may be arranged freely on the light steel flooring. Any load-bearing wall underside, on the axle or vertical direction of partition walls is not required. Such walls constructed by cold-formed steel profiles can also be used as a partition for reinforced concrete or conventional steel structures. Posts of steel partition walls are arranged as to allow assembly of coating elements. Rigidity of join point of these walls not having bearing property should be adequate to make the wall achieve its own stability. As posts are not required to be integrated with each other at joining points, these walls can be arranged freely within the plan. Similarly, these walls constructed independently of each other and the flooring can be removed without any intervention to the load-bearing system. Posts and coatings of the partition wall disassembled can be used for the construction of any other partition wall. Additionally, only any of the flooring and other walls where partition wall is inserted may be disassembled. In order for realization of such a change flexibility, partition wall should be mounted on coating after its ceiling coating is completed [32].

Partition walls can be rearranged on the flooring at any dimension and angle. However, jointing should be made by means of demountable screws or bolts. Walls not having bearing feature are generally made of profiles having less width than 90 mm. Profiles having wall

Table 3: Modular System



thickness between 0.45-0.68 mm are arranged as to have a space of 610 mm. As these walls shall not have load-bearing feature, it is enough for them to bear coating [33]materials to accomplish their partitioning task. Any cross stability is not required as in the case of load-bearing wall or curtain walls. Horizontal sash cords or bars to provide rigidity of the wall and to prevent twisting of posts due to additional tensions that may occur in the scope of the structure. As the posts at joining points are not required to be integrated with each other, these walls may be freely arranged within the plan. Similarly, these walls constructed independently of each other and flooring can be dismounted at any time without any intervention on load-bearing system [33].

In this study, alternatives are searched on the basis of plans consisting of rectangular 2 modules having dimension of 3x7.20m. 31 plan schemes are obtained at the end of this study (Table 4). On the basis of these plan schemes, single and 2-room solutions are improved on an area of 43 m2.

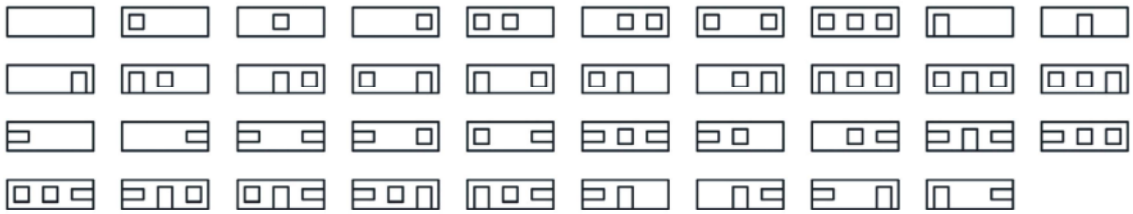
Table 4: Plan schemes consisting of two modules

Following results are obtained at the end of plans made:

- It is identified that a different scheme having max. flexibility can be improved among 2 modules. In total, 40 plan schemes are developed.
- Single and 2-room plan schemes are arranged by 2 modules having a dimension of 3x7.20 m.
- Costs increase in relation with length of the construction. Usage of different flooring at large constructions also increase cost [34]. Therefore, plan schemes should be developed as to provide max. flexibility and max. economy. Accordingly, dimensions should be identified on the basis of these criteria.

Alternative Façade Applications for Modular Plan Schemes of Light Steel System Proposed: As the structural construction of light steel systems consists of load-bearing walls, alternatives for opening spaces on the façade are restricted. Dimensions of gaps created on walls of light steel systems depend on arrangement space of light steel posts. By elimination of intermediate posts, gaps may be opened later as to be multiplies of arrangement space of posts. However, a frame and lintel providing rigidity of the gap should be arranged for structural loads replacing posts eliminated. Similarly, gaps may be closed by arrangement of posts at available gaps [35, 36]. Modular coordination relation may be established between dimension of light steel bearing system elements

Table 5: Fullness/gap rates for long façade



and other elements, such as OSB plywood, gypsum plates or composite façade coatings [37,38]. Such coordination affects façade construction of light steel systems in relation with coating elements. Standard dimension of coating elements and load-bearing system of light steel systems are compatible with each other in the framework of modular coordination. In particular, light steel structures are prioritized during their production with panel construction system [39]. Façade of light steel systems consists of load-bearing walls. Therefore, their construction on the façade is related with the elements constituting the load-bearing wall. Gaps and dimensions of filled parts between the gaps of light steel construction facades depend on arrangement modulation of posts. These dimensions are the multiples of post spaces.

As for light steel systems of the structure, hollow drilling alternatives are limited due to formation of the structural system with load-bearing walls. While analyzing opportunities related with façade construction, design criteria such as "reflection of load-bearing system to the façade and identification of façade construction", "drilling gaps on the façade", "gap dimension", "gap geometry", "façade coating material and texture" may be considered. Modular coordination relation may be established between dimension of light steel bearing system elements and other elements, such as OSB plywood, gypsum plates or composite façade coatings. Such coordination affects façade construction of light steel systems in relation with coating elements. Standard dimension of coating elements and load-bearing system of light steel systems are compatible with each other in the framework of modular coordination. In particular, light steel structures are prioritized during their production with panel construction system. As light steel framework elements can be directly perceived on the façade, modular structure of load-bearing system affects fullness – space rate on the façade and arrangement of these rates. Modular structure brought by the load-bearing system provides establishment of arithmetical relation between fullness and gap rates of the façade. One of the most significant drawbacks of load-bearing walls non-availability of load-bearing elements at door and window gaps and

Table 6: Estimation of all possibilities for the façade

=All possibilities	Filled	Filled	Filled
	Door Window Nook window	Door Window	Door Window Nook window
	4	3	4
48-6-2-1=39			

Table 7: Estimation of number of door possibilities at facades

1 Door	1 Door	1 Window Full	=2
2 Window Full	1 Door	1 Door	=2
1 Door	2 Window Full	1 Door	=2
(2 1 1)x3 =6 **=1			

*Concurrence of 2 doors

** Concurrence of 3 doors

Table 8: Estimation of nook window and door possibilities

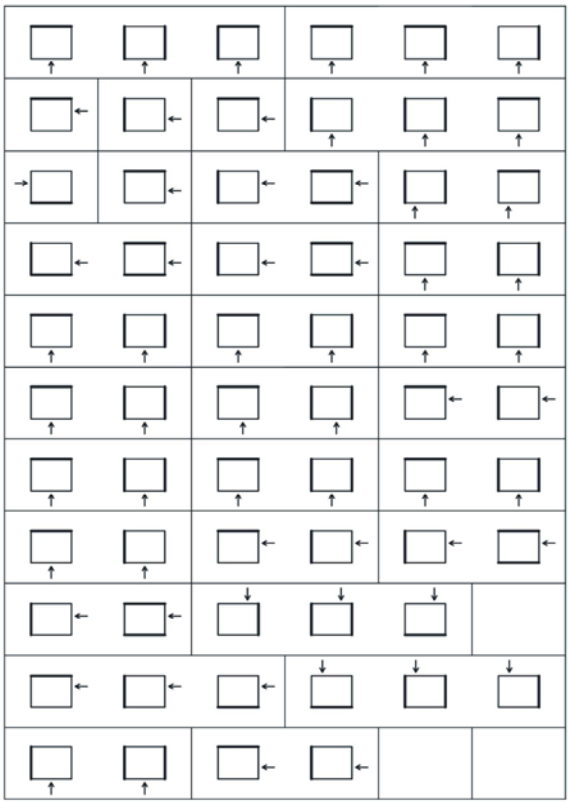
1 Nook Window	1 Door	1 Door	=1
1 Door	1 Door	1 NookWindow	=1 =2*

* Concurrence of nook window together with 2 doors

accordingly, weakening of load-bearing frame. This matter may be eliminated by means of door or window frames made of light steel profiles and a lintel being endurable against loads carried by the wall. By this way, a rigid frame consisting of the frame and lentil is obtained. It consists of lentil, I profile or box profile. If a gap of more than 120 cm is required, upper and lower header and all of the door frame consist of nested double profiles (*multiple members*) [40].

Horizontal and vertical dimensions of space or structure elements, as well as coordination dimensions are selected among multiples of a specific dimensional module during design of the structure. This is named as "standard basic module" and indicated with the symbol M having a size of 10 cm or 4 inch (approximately 4 inch = 10 cm). However, sub-modules such as M/2 or M/5 may also be used during identification of dimensions of elements like wall, flooring, etc. 3M upper module being three times of M module and its multiples are used for larger structure elements. The objective is to provide much more decrease in dimensional diversity reduced through M module through limitation by 3M module. Multiple modules may

Table 9: Filled-empty walls within plan schemes proposed



be obtained by repetition of 3M basic module, such as 3M, 6M, 12M, 15M, 30M…[41,42,43,44]. Table 3 presents long façade surveys of plans schemes on the basis of 3M-modules.

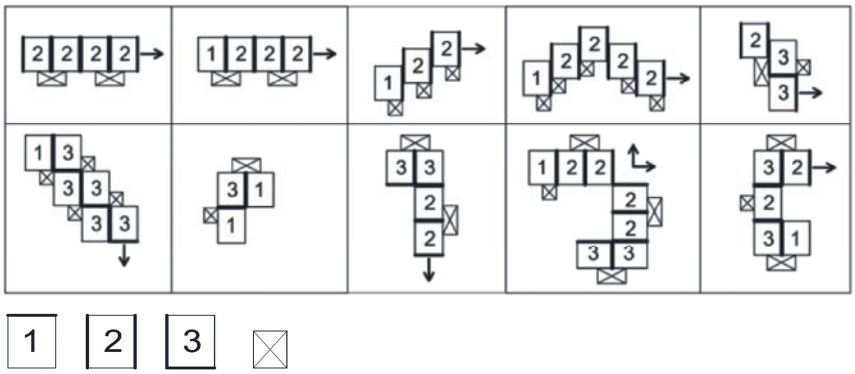
It is difficult to apply plywood and OSB coatings widely used in Turkey and having a dimension of 170x220 cm to the light steel systems in modular form. However, elements produced as to have a dimension of 180x220 cm can be used as an alternative for 170x220 cm. Transverse made against horizontal loads is essential in façade construction. While selecting any of the alternatives indicated in Table 3, transverse points should be considered. As a result of façade surveys applied, 39 façade alternatives are obtained consisting of combination of 4 full units with door, window, nook window, 3 full units having door, window modules and 4 units having door, window frame and nook window.

Places of filled and empty walls are indicated in plan schemes presented in Table 9. Filled walls are shown with dark color; whereas, walls having window and door gaps are indicated with fine lines. Entry door is marked with ok. Arrangements enabling construction of serial residences may be obtained by identification of filled walls (Table 10)

Mass Alternatives for Light Steel Structures: Alternatives for superposition structure of residences in 3-flats whose plan schemes are presented above are indicated in Table 11. Flats of mass arrangement may be arranged as sliding cantilever. This study does not cover cantilever formation stage, as cantilever shall increase plan alternative and façade construction rate.

Optimum Installation Solutions for Residence Plan Schemes having Light Steel System: Gaps required for the installation and stairs of light steel structures should be accomplished as not to create any damage on load transmission property of the flooring. Gap rates to be opened on beams should comply with the regulations. Center of the holes should coincide with the center of the profile and the hole should be drilled minimum 3 cm after the edge of profiles; whereas, the distance between holes should be minimum 4.5cm. Places where installation is to be passed through profiles of light steel structures should be defined earlier. Holes where such installation elements

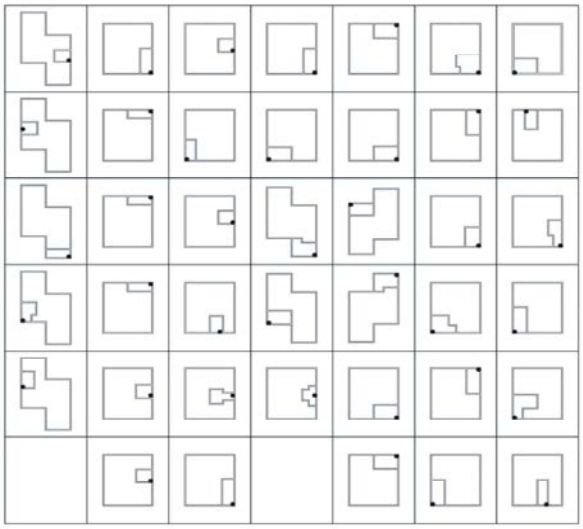
Table 10: Horizontal extendibility of residence plan proposed



1.Wall having one side filled,2.Wall having 2 sides filled,3.Wall having 3 sides filled
X Merdiven gösterimi

Table 11. Mass arrangement alternatives

Table 12: Installation points are indicated with black point within proposed plans.



are to be passed are drilled on upper and lower sides of profiles in the factory. Two gaps for the electrical installation are provided in horizontal direction and one gap for passage of electrical installation is left vertically on the profile. Installation gap should be placed on support sheet of cold profiles. Electrical installation line should be continuous around the structure. Due to the diameter of water installation pipes, thickness of walls where these elements are to be passed should be minimum 14 cm. As for sound insulation, insulation material is used to cover around the pipes. Covers providing easy access to the system in case of any failure should be arranged.

Maximum 8 different places for installation shafts are identified when installation shafts proposed are surveyed with respect to the plan schemes. This figure is obtained via separate counting of right, left and top, bottom corners. If the directions are not counted on the basis of right, left and top, bottom separation, it is identified that 39 plan solutions may be applied with 2 installation shafts. This solution proves that simple, easy and serial construction can be achieved by means of the solutions at the corner and side walls (Table 12).

Evaluation of Criteria considered during Assessment of Light Steel Systems in Modular Residence Construction: Light steel modular residence construction systems are analyzed on the basis of 7 criteria in the scope of this study.

Creation of Different Type Façade Shapes (Design-Arrangement-Production Flexibility)

Facade Construction of Carcass Systems: Light steel structures are constructed on the basis of masonry structure principle, like in the case of wooden carcass. Hole drilling process is applied in accordance with the rules stated by the regulations. As for the places not having earthquake risk, any façade may be obtained by increasing profile dimension and beam dimensions.

Facade Construction of Board Systems: If light steel structures are constructed in the shape of panel system, window gaps to be opened should have a size not deforming stability of the boards; therefore, certain limits should be complied by the window dimensions.

Facade Construction of Modular System: Regarding the systems whose ceiling, flooring and wall elements are produced in the factory in modular form, drilling of window and door gaps should be performed within certain limits and on the basis of stability matter during delivery, handling and assembly process.

Opening of Gaps at the Corner of Light Steel Structures: Due to the application of masonry structure principle, opening of holes at the corners of light steel structures in not proposed. However, it is possible to open gaps on related sections by increasing lentil height in the scope of special applications.

Drilling Gaps in the corner of Carcass Systems: The post at joining point of two facades may be established by means of combined profiles and like a column. Under certain conditions, gaps may be opened in the corners. First of all, rigidity of the corner and accordingly the structure should be provided by the light steel. Therefore, a frame resisting against the moment should be created in the corner.

Drilling Gaps in the corner of Board Systems: According to the light steel production principles, opening of gaps in the corner is not recommended. Like in the case of masonry structures, rigidity of the structure is extremely important in the corner points. Corners are the points where load-bearing walls support each other against horizontal loads. Gaps to be opened in the corners strengthen support of load-bearing walls. In addition, light steel curtain walls formed by means of transverse are arranged as to be close to each other resulting with deafness at these points.

Drilling Gaps in the corner of Module Systems: Opening of gaps in the corners of module systems is not recommended due to the stability problems that may occur during delivery, assembly. Nook windows may be opened by taking necessary precautions and by increasing beam, lentil height.

Evaluation of Partition Walls in terms of Arrangement Easiness

Partition Wall Arrangement of Carcass Systems: Partition walls of carcass systems can be arranged effectually. As loads encountered by the structure are transferred safely to the foundation, any restriction related with partition wall arrangement is not in question.

Partition Wall Arrangement of Board Systems: After handling and safe placement of boards separately, board systems may be connected to each other in rigid form as a result of which load encountered by the system is transferred to the flooring and the foundation from the wall. Such a partition wall arrangement may be applied in any masonry construction system.

Partition Wall Arrangement of Module Systems: In cases where modules delivered to the site as a produced finished within the factory should not exceed certain weight level, number of partition walls may be restricted.

Evaluation of the System in terms of Story Height: Replacement of load-bearing walls of light steel systems is more difficult when compared to the partition walls. First of all, structure should be suspended and structure loads should be carried by this suspension systems in order for application of any change related with the load-bearing walls.

Evaluation of Carcass Systems in terms of Story Height: Different story heights may be applied for carcass systems. As truck dimension is max. 13.5m, profiles of carcass systems may be produced as to reach this dimension. Such long profiles are not used for light steel structures. Therefore, it is possible to obtain desired height in the scope of carcass systems in relation with construction conditions.

Evaluation of Board Systems in terms of Story Height: Story height is 2.60 m for board systems in relation with delivery conditions.

Evaluation of Module Systems in terms of Story Height: Story height is 2.60 m for module systems in relation with delivery conditions.

Evaluation in terms of Installation Passage Facility in Horizontal-Vertical Direction

Installation Passage Facility of Carcass Systems in Horizontal-Vertical Direction: Establishment of the system by passing installation systems through the profiles of carcass system is possible after taking certain precautions related with profile sections.

Installation Passage Facility of Board Systems in Horizontal-Vertical Direction: Board systems may be produced with finished installation systems, insulation and façade coatings or in semi-finished manner in which case installation systems shall be passed through gaps opened on profiles and insulation, as well as façade coating is to be applied later. Insertion of installation system is easy.

Installation Passage Facility of Module Systems in Horizontal-Vertical Direction: Installation systems are placed to the module systems under supervision within the factory. Placement of the installation is as easy as the carcass and board systems.

Evaluation in terms of Passage of Large Opening: The most efficient system in both directions and in terms of opening between the supports is the grill system having 11.x8m opening.

Evaluation in Terms of Passage of Large Opening Through the Carcass Systems: It is recommended for carcass systems that max. light steel structure width (in parallel direction to the flooring beams) should be max. 11 m and length (in vertical direction to the flooring beams) should be max. 18 m. The largest space that may be obtained by means of light steel structure systems is 6 m in width and 18 m in length.

Evaluation in terms of Passage of Large Opening through the Board Systems: Board dimensions of board systems may differ in accordance with various criteria, such as delivery and lifting of crane and placement. Board dimension is 30m and its multiples.

Evaluation in terms of Passage of Large Opening through the Module Systems: Dimension of modules depends on truck dimension of 3.2x13.65 m. Max. module dimension shall be 13.5m.

Extendibility: Additions may be required to the structures made by light steel system due to functional change and/or inadequate functions. In such cases, foundation and light steel bearing system of additions should be arranged as a separate structure. By this way, dilatation created in-between the current structure enables functioning of additional part as a separate system from the current structure. Floorings are placed on headings of load-bearing walls. Light steel systems have high recycle feature. It is possible to dismantle and construct the system anywhere in the future. Additions to the system can be made easily by means of dry joins (Table 8).

Extendibility of Carcass Systems: Modification, extension of the carcass system with respect to the changing needs is applied by means of units fixed to the external bearer without any intervention on current load-bearing system of the structure.

Extendibility of Board Systems: Board systems support future extendibility when necessary precautions are taken.

Extendibility of Module Systems: Module systems do not require additional transverse and other supports being easily extendable in terms of the bearer.

Stair Enclosure: With respect to the carcass system, board and module systems, stairs can be applied with and without aisle as to reach maximum 2 residences (Table 10).

Evaluation in Terms of Production Time: It presents spatial organization and façade arrangement facility. As the connections of the elements used in the scope of the system are dry, it is possible to provide changeability of the residences in relation with the space by dismounting and placing the system and adding new units to the residences. The system has high flexibility rate. Modular coordination level and completeness level of the elements constituting the system is extremely high. It is also efficient in terms of number of load-bearing system elements, different element figures and connections. Crane is required for assembly of board and cell systems. It is possible to dismantle the system and use it anywhere.

External wall of residences should present appropriate values in terms of heat insulation.

Structure shell is efficient in terms of water and humidity insulation. Material of bearing system easily accommodate with other materials. As the walls may be produced in any thickness, the system is productive in terms of adaptation to different climatic conditions. Its fire resistance level is high. Utilization of rigid materials in walls, flooring, roof systems provides high noise insulation values.

In accordance with load-bearing system principles of light steel construction systems, formation of gaps on load-bearing walls is limited. Therefore, façade construction is much proper for small structures, like residences. As light steel systems are weaker than conventional systems in terms of fire impact, they are recommended for 1-3-storey structures where evacuation is easier. When limited gap passage of light steel elements is considered, it may be commented that sight steel systems are appropriate for structures like residence not requiring large gaps. In addition, light steel structures should be used for lower-story structures, as structural difficulties shall be encountered after three stories, in particular the carriage of horizontal loads shall create difficulties.

Table 14 presents evaluation of plan schemes of 3 different light steel structures in terms of construction and utilization processes. According to these evaluation

Table 13: Scores of three different light steel construction systems in terms of their construction process in the scope of plans proposed.

Evaluation Criteria	Carcass system	Board system	Module system
Evaluation in terms of formation of different type of façade structures (design-arrangement-production flexibility)	3	2	2
Opening gaps in the corner of light steel structures	2	3	1
Evaluation in terms of partition wall arrangement facility	3	3	3
Evaluation in terms of story height of the system	2	1	1
Evaluation in terms of passing installation in horizontal-vertical direction	3	3	3
Evaluation in terms of passage of large gaps	2	1	1
Extendibility	1	2	3
Arrangement of stairs	2	2	2
Total	13	17	16

Not: 3 good, 2 medium, 1 bad

Table 14: Evaluation of 3 different light steel construction system in terms of their production process defined within the plan schemes

Criteria		Carcass System	Board System	Modular System
Production Process	Low investment cost	3	2	1
	Utilization process	2	3	3
Design process	Rational design with optimum resource	3	3	3
Construction process	Short	2	3	3
Utilization process	Sustainability of technical life of residences with min. maintenance and repair	3	3	3
	Easy maintenance and repair works	3	3	3
	Min. energy, etc. resources during utilization period	3	3	3
Technical purposes related with the structure	Compatible with earthquake conditions	3	2	2
	Opening of any gap at structure shell	2	2	2
	Extendible with utilization flexibility	2	2	2
	Sufficient heat and water insulation	2	2	2
	Fire resistive	2	2	2
	Easy to handle	3	2	1
	Easy assembly	3	3	3
	Total	35	35	15

criteria, carcass system and board system have similar scores; whereas, score of module system is less due to different processes required to be applied during its production stage.

CONCLUTION

Light steel load-bearing systems can be used in 3 different forms named as carcass, board and module systems. The system provides various opportunities such as controlled production of system components in the factory, advanced performance values, safety against earthquake, presentation of architectural diversities to the designers, flexible opportunities meeting changing user needs and short construction period of the structure. In this research, it is obtained that a residence plan consisting of 2 modules each of which has a dimension of 3x7.2 and having a size of 6x7.2m and located on an area of 43m2 can be surveyed in different methods. It is observed that various arrangements are possible through planning alternatives and façade, as well as mass related alternatives. Through this system proposed due to above stated features, it is possible to construct recyclable residences rapidly, securely and with rich alternatives, high comfort conditions for low-income families, urban transformation projects and places where fast and economic residence construction is required. It is supposed that such a construction technology that may be applied under various conditions shall contribute to the residence sector and country economy. Therefore, the flow from production stage to the delivery to the end-user stage of 3 different construction systems should be well-known and selection should be made with respect to the priority of selection criteria.

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