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MASONITE FLEXIBLE BUILDING SYSTEM FOR MULTI-STOREY TIMBER BUILDINGS

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ABSTRACT: The Masonite Flexible Building (MFB) system is a complete timber building system for commercial and residential multi-storey houses. The system is subdivided into two market variants; XL and Light. The XL version is for tall and large buildings with long floor spans while the Light version is adapted for smaller buildings with lower loads. Though differing in technical performance, the functional criteria are the same for both variants. The MFB system uses prefabricated wall, floor and roof elements which are delivered in flat packages and erected on the construction site. The MFB system might be classified as a panel construction, where the load-carrying structure consists of composite light-weight timber I-beams mechanically integrated with a composite laminated wood panel called PlyBoard™. The I-beams and the panel form a strong and rigid carcass for wall and floor elements, making the system well suited for high rise construction. A key feature of the MFB system is the connection technique which enables swift erection of the system units on site. The plyboard panels are provided with a continuous slot along the periphery. The slot is used as a general connection interface for the joining of the wall elements. The floor elements are suspended and hooked onto the bearing walls using sheet steel hangers, allowing swift assembling of the floor deck and enabling direct vertical wall-to-wall load transfer parallel to grain. The paper presents the construction principles, system components and units, erection technique and functional and architectural aspects of the Masonite Building System.

KEYWORDS: Masonite Flexible Building system, multi-storey timber buildings, slotted-in connections, suspended connections, functionality requirements.

1 INTRODUCTION

Building systems and construction methods for multi-storey timber buildings have developed rapidly. Today, timber construction technology uses prefabricated units, which are highly competitive with regard to cost efficiency, environmental impact and erection. The Masonite Flexible Building (MFB) system is one of several systems based on prefabricated units.

The MFB system is an open building system in the sense that the technical solutions and the building method are free to be employed by architects, designers, manufacturers and construction companies. The system meets current requirements regarding fire safety, moisture conditions, strength and stabilization, thermal and acoustic insulation. The system is subdivided into two market variants; MFB XL and MFB Light [1]. The XL system is aimed for large multi-storey buildings up to 8 storeys high and floor spans up to 8 meter while the Light version is cost optimised for detached houses and smaller buildings with lower loads and floor spans. The main difference between the system variants is the structural design of the floor and the wall elements. The XL system is a modified panel construction featuring a special composite laminated wood panel called PlyBoard™, I-beams and I-studs whereas the Light system is a conventional stud and sheathing construction. Though differing in technical performance, the functional demands are the same.

The two variants can be combined in multi-storey building to obtain a cost-effective solution. For example the Light system can be used in the upper storeys where the vertical loads and horizontal wind forces have not yet developed in magnitude, while the XL system is used in the lower storeys. This paper focuses on the XL system.

2 THE MFB XL SYSTEM

The XL system consists of prefabricated wall, floor and roof elements which are delivered in flat packages and assembled storey by storey. The system is intended for multi-storey buildings up to 8 storeys and the floor spans up to 8 m. The system meets fire requirements of REI 60 (Swedish Building Rules, BBR 5:221) and noise requirement class A (Swedish Standard, SS 02 52 67).

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Structurally XL is a panel construction with linear and plane wood-composite members. Prominent features are the plyboard panel with its unified connection interface, elimination of horizontal timber members in the walls to reduce settlement to a minimum and the suspended floor-to-wall connection. The carcass structure and the high quality of system components offer architectural freedoms and simple assembling.

2.1 LOAD-BEARING STRUCTURE

External wall and floor elements use a ribbed plyboard panel construction with ribs of composite I-studs and I-beams, respectively. Internal wall elements may have, depending on the magnitude of load and application, a ribbed or boxed plyboard panel structure with ribs of squared timber studs. The different load-bearing structures are depicted in Figure 1. The plyboard panel is attached to the I-beams/I-studs mechanically by nails. The combination of plyboard and I-studs/I-beams forms a strong and rigid load-bearing structure well suited for high rise construction, see Section 2.2.1 and 2.2.2 for description of each of the structural members.

Usually in wall panel constructions, the individual studs carry the vertical loads from roof and suspended floors whereas the sheathing resists the horizontal forces due to wind and accounts for the bracing. In this case, the plyboard panel is employed for carrying both vertical and horizontal loads, thus significantly increasing the load-bearing efficiency of the walls. The use of high quality engineered wood products offers new design options which improves many of earlier disadvantages for multi-storey timber buildings, such as vertical settlement due to loading perpendicular to grain of horizontal members, thermal bridges at wall-to-floor junction etcetera.

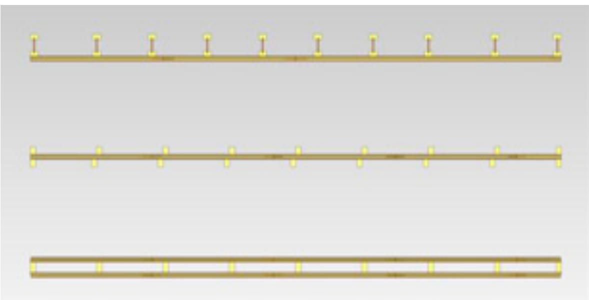


Figure 1. *Examples of structural wall and floor carcasses used in the XL system; Top: Ribbed plyboard panel with I-studs/I-beams used in external walls and floor; Middle: Double ribbed plyboard panel for internal walls; Bottom: Boxed plyboard panel for internal walls.*

2.2 MATERIAL AND SYSTEM COMPONENTS

The structural components of the XL system are a composite light-weight I-beam and a plyboard panel. Together they constitute the structural skeleton of the building elements.

2.2.1 Composite I-beams

The composite I-beams and I-studs are used as structural members in wall, floor and roof elements. The flanges are made of machine graded structural timber, and the web is made of hard fibreboard or OSB, see Table 1.The different types of beams and studs pertinent to the MFB system are compiled in Table 1. The I-beams/I-studs are manufactured by Masonite Beams AB [2].

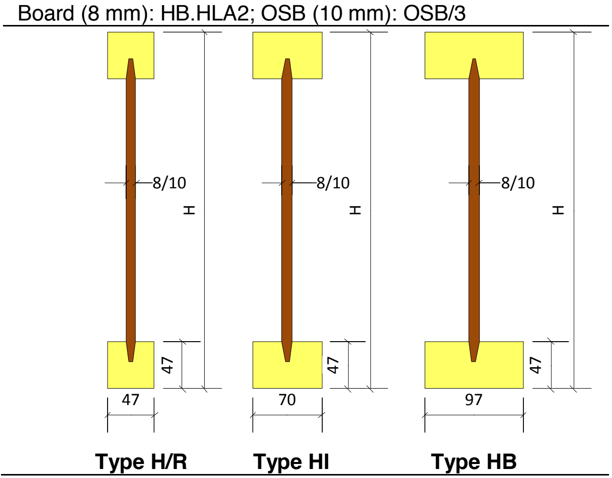
Table 1. *Characteristics of I-beams and I-studs in the MFB System. Height and weight of beams (H, HI, HB) and studs (R) with web of hard fibreboard or OSB.*

H [mm]	Weight [kg/m]					
	Type H / R		Type HI		Type HB	
	Board	OSB	Board	OSB	Board	OSB
200	3,1	2.8	4,0	4.3	5.5	5.4
220	3,2	3.0	4,2	4.5	5.3	5.6
250	3,4	3.1	4,4	4.8	5.6	5.9
300	3,8	3.5	4,8	5.2	6.0	6.4
350	4,2	3.8	5,2	5.7	6.3	6.9
400	4,6	4.1	5,6	6.2	6.7	7.3
450	5.0	4.4	5,9	6.7	7.1	7.8
500	5.3	4.7	6,3	7.1	7.5	8.3

Standard length [m]
H, HI, HB: 6.4, 7.8, 9.0, 10.2, 11.6, 13,3; R: 6.0, 7.5.

Strength class flange
H, HB: C30; HI: C30 (H<300 mm), C24 (H≥300 mm); R: C18

Strength class web
Board (8 mm): HB.HLA2; OSB (10 mm): OSB/3



2.2.2 Plyboard panel

PlyBoard™ is a three-layered wood composite panel with a core of LVL and surface layers of hard fibreboard as shown in Table 2. The veneer plies have a thickness of 3-4 mm and the grain orientation is parallel for all plies. The material composition gives the panel high strength and stiffness, good form and dimensional stability and high diffusion resistance. The panel is available with fibre board thicknesses of 4 or 8 mm and number of LVL plies between 3 and 7. Format dimension is 1200× 2400 mm. Manufacturer is IBC Group [3].

In order to achieve a continuous panel which extends the full length of the wall and floor elements the individual panels are spliced using a loose tongue joint which is glued to attain a strong joint, and for external walls also airtightness and vapour barrier, see Figure 2.

2.3 WALL ELEMENTS

Decisive for the design of the wall elements are the way the building is used, the building physics and energy and acoustic related requirements.

Table 2. *Characteristics of PlyBoard, a three-layered composite panel with core of LVL and surface layers of hard fibreboard. The panel is employed as a load-bearing member in wall, floor and roof elements.*

Model	Thickness of board [mm]	No. of plies	Total thickness [mm]	Weight [kg/m^2]
P43	4	3	19	14.8
P45	4	5	27	19.7
P47	4	7	34	24.7
P83	8	3	27	22.1
P85	8	5	35	27.1
P87	8	7	42	32.0
Standard dimension [mm] 1200×2400 mm.				
Strength class: Board: HB.HLA2.				

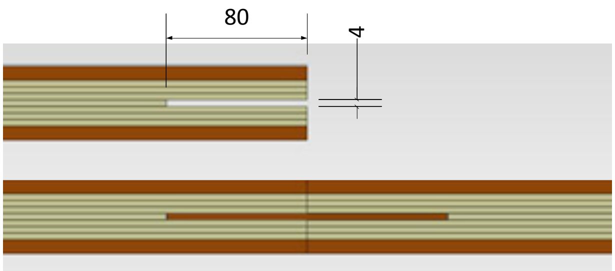


Figure 2. *Plyboard panel; Top: Periphery slot; Bottom: Spliced panels using a glued board tongue joint. Dimensions in mm.*

All the wall elements are delivered with preinstalled tubes for electric cables and power sockets. The maximum lengths of the wall elements are limited to 9 m due to what can be transported by road.

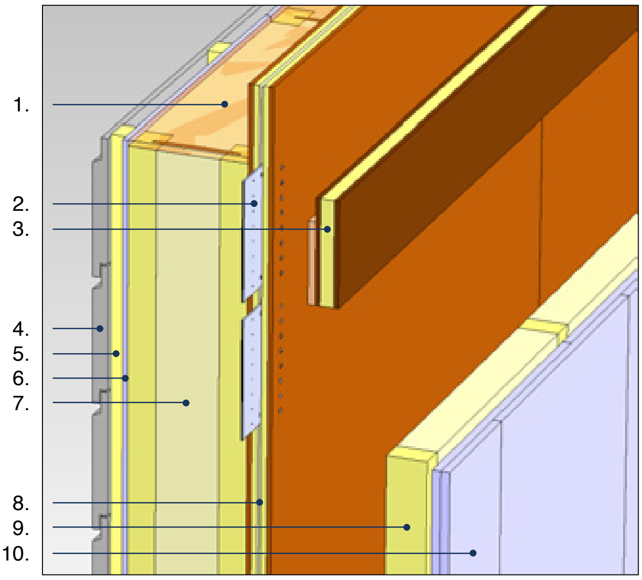
2.3.1 External wall elements

The external wall elements are delivered with cladding, doors and windows and a perimeter beam for the suspend-ed floor. The carcass is a ribbed panel structure accord-ing to Figure 1 with I-studs and a plyboard panel shown in Table 1 and Table 2.

Figure 3 shows a representative external wall construct-ion with a description of each of the various layers and parts. The depth of the load-bearing layer is normally 200-400 mm depending on the demand of thermal insulation. The plyboard panel is attached to the inside of the I-studs. This enables the vertical loads to be transferred directly to the foundation, and is further favourable for the building physics as the dense plyboard can perform the triple functions of bracing, airtight membrane and vapour barrier provided that the panel splices are tightened and sealed.

Due to the continuous panel sheathing and the suspended floor connection, which structurally disconnects the wall from the floor, the building envelope remains completely intact and unbroken. Combined with the low thermal transmission profile of the I-studs the thermal bridges are hence reduced to a minimum, making the wall design well adapted for highly insulated buildings.

An issue of great importance with respect to high rise timber construction is the settling due to horizontally installed timber members in the wall and floor. Subsequently, the proportion of load-bearing horizontal members in the XL external walls is reduced; the top and bottom plates are replaced by head and sole strips of hard fibre board.



1	Head and sole fibre board strip (transparent)	10 mm
2	Slotted-in wall-to-wall connection plate	
3	Perimeter beam for suspended floor	P47/P85, Table 2
4	External cladding	Variable
5	Framework of battens with ventilation cavity	28x70 mm s_{600}
6	Wind protection sheet	9-13 mm
7	Framework of I-studs and thermal insulation	200-400 mm s_{600}
8	Plyboard panel with perimeter slot	P87, Table 2
9	Framework of battens for building services	45x70 mm s_{450}
10	Inner lining of double plasterboards	2x15 mm
	s_{600} = 600 mm, s_{450} = 450 mm	

Figure 3. *The XL external wall element with carcass of plyboard panel and I-studs.*

2.3.2 Internal wall elements

The internal walls have either a doubled ribbed panel or a boxed panel structure according to Figure 1, with squa-red timber studs as shown in Table 1 and Table 2 respectively.

Like the external walls, internal walls carry the loads from the roof, suspended floors and the dead load of the wall itself. Furthermore, they are used for bracing the building implying that they transfer the horizontal wind force and the wind induced uplift force. Figure 4 and

Figure 5 show two types of internal walls including descriptions of each of the layers and parts.

2.4 FLOOR ELEMENT

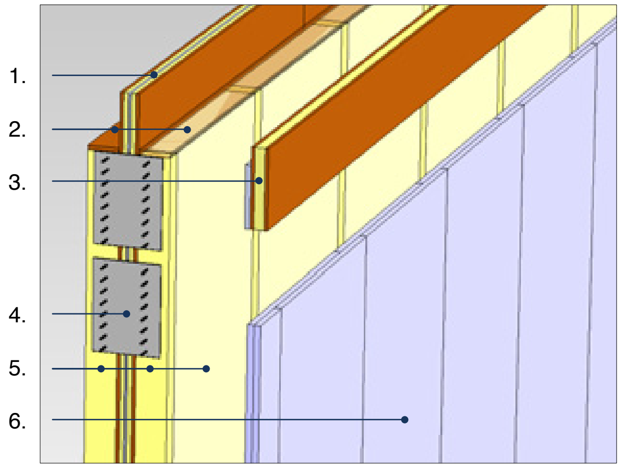
Floor structures have to offer adequate load-carrying capacity, minimal deflection and vibration, effective sound insulation and sufficient fire resistance. To satisfy these demands, the XL suspended floor elements are designed as a multi-layered structure with an embedded load-bearing structure, a floor finish and a ceiling as illustrated in Figure 6. The structural floor layer is a composite ribbed plyboard panel according to Figure 1. The floor elements are prefabricated and delivered with pre-attached floor hangers and resilient ceiling.

To obtain good sound insulation and vibration properties heavyweight finishes are advantageous. The plyboard panel itself adds weight and stiffness, and distributes the acoustic energy laterally enhancing the acoustic performance. A supplementary sub-floor of dry sand fill or similar material can be added to further improve the sound insulation. The floor finish consists normally of a double layer of floor plasterboard on top of a single layer of floor particleboard, see Figure 6. The ceiling is pre-attached to the floor element at manufacturing by ceiling-hangers to achieve resilient fixings. The ceiling-hangers allow the ceiling to be displaced against the bottom flange of the I-beams to enable vertical stacking of floor elements during transportation. Beneath the fixings a double-layer of acoustic plasterboards is used.

An essential issue of a suspended floor is the design of the wall connection which has to fulfil multiple demands. It should not only transfer the self-weight and the imposed load of the floor, but also eliminate acoustic flank transmission to nearby compartments, be fire resistant and allow for easy erection of the floor elements.

The MFB system uses sheet metal hangers that are pre-mounted on the ends of the floor element with mechanical fasteners and hooked on to a separate perimeter beam on the wall when the floor element is lifted in place. The design of the floor hanger is described more in Section 2.5.3. The choice of a floor-to-wall connection that is structurally disconnected from the external wall carcass is governed by four principles:

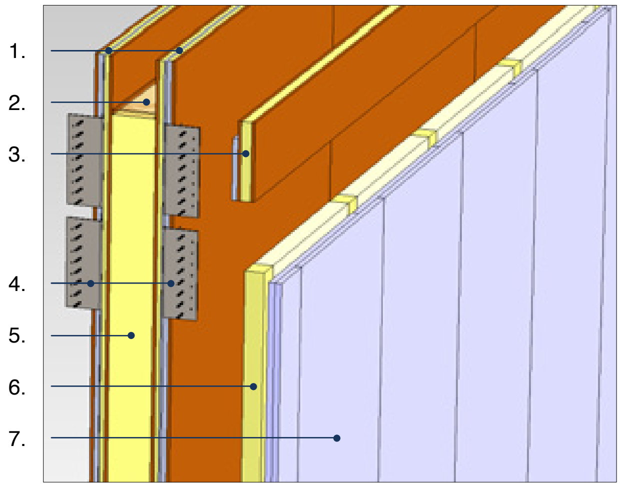
1. By placing the floor "beside" the wall, loading of horizontally installed timber members perpendicular to grain is avoided, hence there is no contribution of the floor to the settling of the wall.
2. The floor connection should not interfere with the integrity of the wall by penetrating the building envelope, causing thermal bridges and/or harm to the airtightness and vapour barrier.
3. The floor assembling should be simple and swift.
4. The connection should accommodate erection tolerances and moisture induced dimensional changes without affecting the structural integrity of the wall.



1	Plyboard panel with perimeter slot	P87, Table 2
2	Head and sole fibre board strip	10 mm
3	Perimeter beam for suspended floor	P47/P85, Table 2
4	Slotted-in T-bracket plate	
5	Framework of double studs and insulation	45x70-150 mm s_{600}
6	Inner lining of double plasterboards	2x15 mm

s_{600} = 600 mm

Figure 4. *XL internal load-carrying wall element with a single mid panel layer. This type lacks framework of battens for building services and works as a shear wall within or between apartments.*



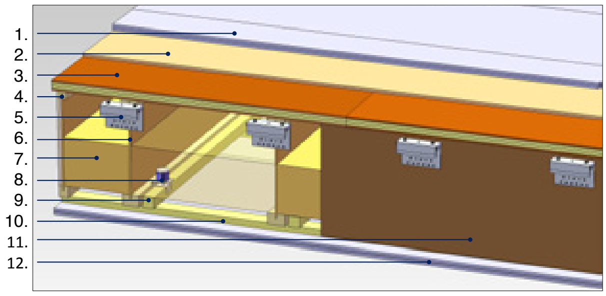
1	Double plyboard panels with perimeter slot	P87, Table 2
2	Head and sole fibre board strip	10 mm
3	Perimeter beam for suspended floor	P47/P85, Table 2
4	Slotted-in transverse wall connection plate	
5	Framework of double studs and insulation	45x70-150 mm s_{600}
6	Framework of battens for building services	2x45 mm s_{450}
7	Inner lining of double plasterboards	2x15 mm

s_{600} = 600 mm; s_{450} = 450 mm

Figure 5. *XL internal load-carrying wall element with a boxed panel. This type has a higher load capacity than the type in Figure 4, and works as a shear wall within or between apartments.*

2.5 STRUCTURAL CONNECTIONS

The XL system has a unified interface for the inter-connection of wall elements and a hanger attachment for the suspended floor to the load-bearing walls. Depending on the type of wall intersection, different types of slotted-in steel plates are used.



1	Double layer of floor plasterboard	2x12.5 mm
2	Floor particleboard	22 mm
3	Plyboard panel	P87, see Table 2
4	Edge I-beam	Type H, Table 1
5	Floor element hanger	
6	Interior I-beam	Type HI/HB, Table 1
7	Sound insulation	200-300 mm
8	Resilient ceiling hanger	
9	Ceiling rib	45x45 mm s 600 mm
10	Ceiling batten	28x70 mm s 300 mm
11	Plyboard rim beam (partly cut)	P87, Table 2
12	Two layers of ceiling plasterboards	12.5 + 15 mm

Figure 6. *The XL floor element with plyboard panel and I-beams. The element is designed for a simply supported span up to 8 meter, acoustic insulation class A and fire resistance class REI60.*

2.5.1 The slotted-in wall connection

The external and internal wall elements are spliced by slotted-in steel plates and screws. The plates are at manufacturing pre-installed in the slot of the plyboard panel along the bottom edge and one of the vertical end edges. At erection the protruding part of the plates go into the opposite slot of the already erected wall elements. When fixed in position remaining screws are fastened. The connection interface is shown in Figure 7 for an external wall and in Figure 8 for a wall junction. The periphery slot enables flexibility as the number and the location of the plates along the sides of the wall element, as well as the screw configuration readily can be adapted to prevailing loading conditions. The slotted-in plate connection resists both horizontal wind force and wind induced uplift forces. Thus, elaborated tie-down arrangements are not needed. The structural features of the slotted-in connection are described in [4].

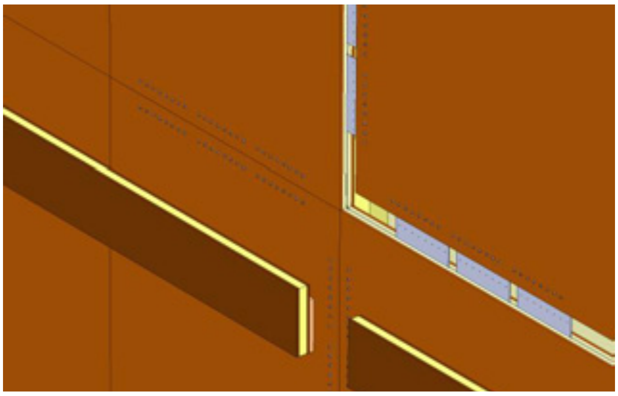
2.5.2 Wall junction and corner connections

The slotted-in plates are also applied for wall junction and wall corner connections. Internal wall elements with a double-ribbed panel carcass use T-brackets, Figure 4. Internal wall elements with a boxed plyboard carcass use angle brackets, Figure 5 and Figure 8. The number of brackets, screw configuration and location along the wall edges depend on prevailing loading conditions. The slotted-in brackets enable a more efficient stabilization of the building by transferring the wind induced up-lift forces from shear walls to transverse walls over the height of the wall and thus avoid local force concentration.

2.5.3 The floor hanger connection

The floor-to-wall connection is critical and needs special design attention as conflicting structural and functional demands coincide, e.g. securing load transfer, avoiding acoustic flank transmission and fulfilling the fire safety regulations. The hangers are preinstalled on the ends of the floor elements and are fastened by screws to the rim beam as shown in Figure 6 and Figure 9. The internal spacing of the hangers corresponds to the spacing of the I-beams of the floor element, normally 600 mm. At erection, the hook of the hanger grabs around the perimeter beam on the bearing walls (cf. Figure 7), enabling direct vertical wall-to-wall load transfer parallel to grain.

It is noticed that the design of the hanger connection suggested by the company can be critical, since there is no redundancy and the safety of the structure depends solely on the hanger in case of failure. The present design is critically examined and evaluated in [5] together with suggestions for improvements and a proposal for an alternative design.



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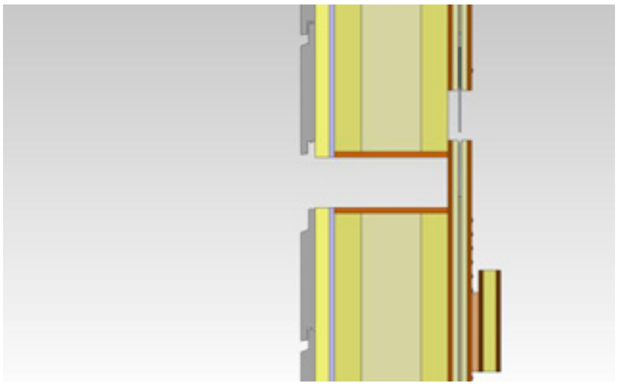

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Figure 7. *External wall-to-wall connection interface with slotted-in steel plates and screw connectors. (a) The steel plates brace the wall and transfer horizontal wind load and vertical up-lift forces down to the foundation; (b) Solid timber head and sole plates in conventional wall construction are replaced by hard fibreboard strips to minimize settlement.*

3 ERECTION ON SITE

The wall elements are erected in storey-high sections and stabilized before the floor elements are put in place to form the deck which becomes the working platform for the next storey. After completion of each storey, all wall splices are sealed with an airstop tape to grant an intact and continuous building envelope.

4 FUNCTION AND ARCHITECTURE

The MFB system is designed with a holistic perspective, unifying diverse design options, safety and functional requirements.

4.1 Acoustic aspects

The concept of suspended floor implies that the floor load is the same for all storeys, and that the same type of acoustic damper can be used for all the hanger connections simplifying the design significantly. The acoustic dampers are pre-attached to the hangers, no additional adjustment or complementary installation is needed on the site. Hence, the risk for mounting errors during erection is low.

4.2 Sustainability and energy performance

The fact that buildings presently account for 40 % of the energy consumption, have led the European Union (EU), because of environmental and sustainability concerns, to introduce legislation to ensure significant reduction of energy use. The EU Directive on energy performance of buildings [6] calls on the member states to make national plans that by the end of 2020 ensure that new constructions are nearly zero-energy buildings, thereby reducing both energy consumption and carbon dioxide emissions. The plyboard panel and the I-beams/I-studs constitute a strong and tight structure and building envelope characterized by efficient use of raw material, good thermal and building physical features, making the MFB system suitable for buildings with very high energy demands.

4.3 Architectural freedom and design flexibility

The prefabricated wall units have a modularized design and can be customized with respect to size and configuration of openings (number, size and location) providing flexibility in organizing rooms' shape in plan, section and size. The stiffness and strength of the floor elements, allowing free spans up to 8 m, add further design options regarding spatial form and proportions. The wall elements allow the building envelope to be optimized regarding structural and physical performance, and both the wall and floor elements can be adjusted to meet specific safety and functional requirements (e.g. thermal, acoustic and fire performance) by modifying or changing components and internal layer composition.

5 CONCLUSIONS

The Masonite Flexible Building System combines the slenderness of a timber light-frame system with the strength and robustness of a cross laminated timber system. The erection of the elements of the system is simple and swift by efficient slotted-in steel-plate connections for the walls and steel hangers for the floors. The system is well adapted for multi-storey buildings.

ACKNOWLEDGEMENT

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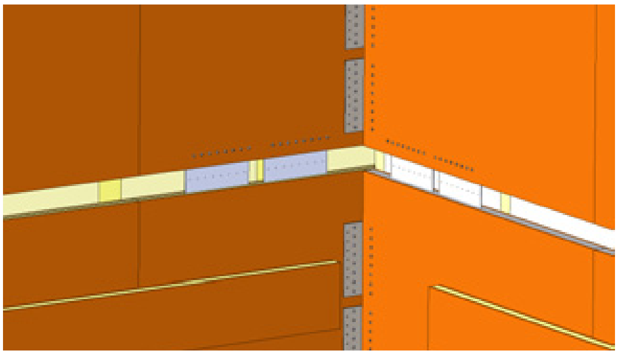
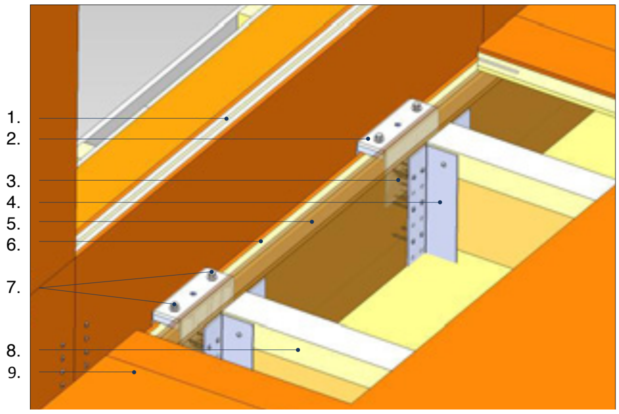


Figure 8. *Wall junction connection between external wall (left) and internal wall (right) using steel angle brackets and screw connectors. The angle brackets transfer part of the wind induced up-lift forces to the external wall, introducing a more efficient load transfer at wall junctions.*



1	External wall plyboard panel	P87, Table 2
2	Floor element hanger	
3	Hanger fasteners in rim beam	Anchor screws 5x40 mm
4	Joist hanger	
5	Rim beam (shown transparent)	P87, Table 2
6	Perimeter beam for suspended floor	P47/P85, Table 2
7	Lock screws fixed to perimeter beam	
8	Interior I-beam	Type HI/HB, Table 1
9	Floor plyboard panel	P87, Table 2

Figure 9. *The XL floor hanger connection for the suspended floor to external wall viewed through a cut in the plyboard panel.*

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