STRUCTURAL TIMBER ASSOCIATION
Building solutions in timber

Structural insulated panel construction

Introduction

Structural insulated panels (SIPs) are engineered, load-carrying, timber-based panel products that can be used in walls and roofs of residential and light commercial buildings. These lightweight panels combine the structural and thermal envelope of the building; they are manufactured off site in a factory and shipped to the construction site (Figure 1), offering advantages to the build programme. This panelised form of construction allows SIPs to be assembled to form highly airtight, energy-efficient building envelopes.

How are SIPs made?

Generally, SIPs are made by sandwiching a core of rigid foam insulation between two structural skins, though many different variations (based on facing and core materials) are included in the blanket definition. SIPs are commonly made using oriented strand board (OSB) as a facing material, although other materials, such as non-combustible cementitious or magnesium oxide boards, can be used.

The most common insulating core materials are expanded polystyrene (EPS) or polyurethane foam (PUR), but other forms of rigid insulation can be used as well, provided sufficient technical data is available.

SIPs are typically available in thicknesses ranging from 100mm to 285mm. They are available in panel sizes up to 2.7m wide and can vary in length from 0.6m to 6.0m. Custom sizes are available and some manufacturers offer curved SIPs for curved roof applications.

For details of different SIP manufacturers, refer to the Structural Timber Association (STA) website: www.structuraltimber.co.uk/members

Facing materials

Ideally, SIP facing materials should have high stiffness, high tensile and compressive strength, high impact resistance, a quality surface finish, resistance to environmental impacts (e.g. chemical, ultraviolet (UV) radiation, heat) and durability. Table 1 indicates the most common facing materials used in SIPs and examines their positive and negative performance attributes.

Core materials

The core materials are responsible for providing thermal insulation, counteracting shear and transverse forces, and resisting moisture penetration. The insulating core also reduces the overall panel weight. When using EPS insulation, the facing material is generally bonded using structural adhesives. PUR foams are commonly injected between the facing sheets; as the foam expands, it forms its own bond with the facing material. Table 2 gives indicative performance characteristics for PUR and EPS core materials. For design purposes, accurate material properties should be obtained from the relevant manufacturer.

Figure 1
Prefabricated structural insulated panels being craned into position

STRUCTURAL TIMBER ASSOCIATION
Building solutions in timber

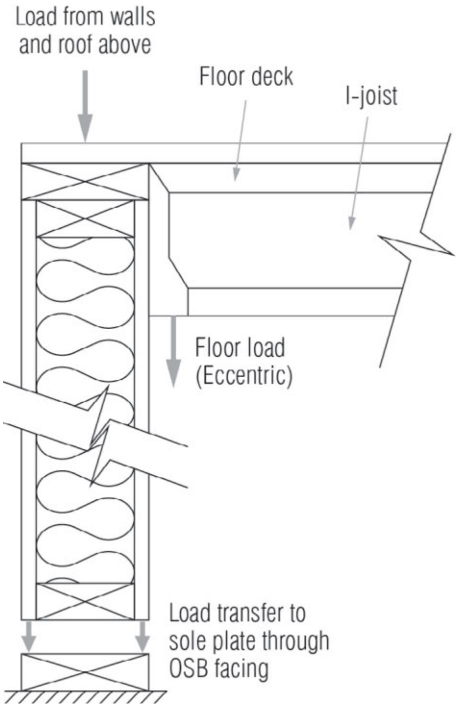

Figure 2
Transfer of vertical load through SIP wall to sole plate

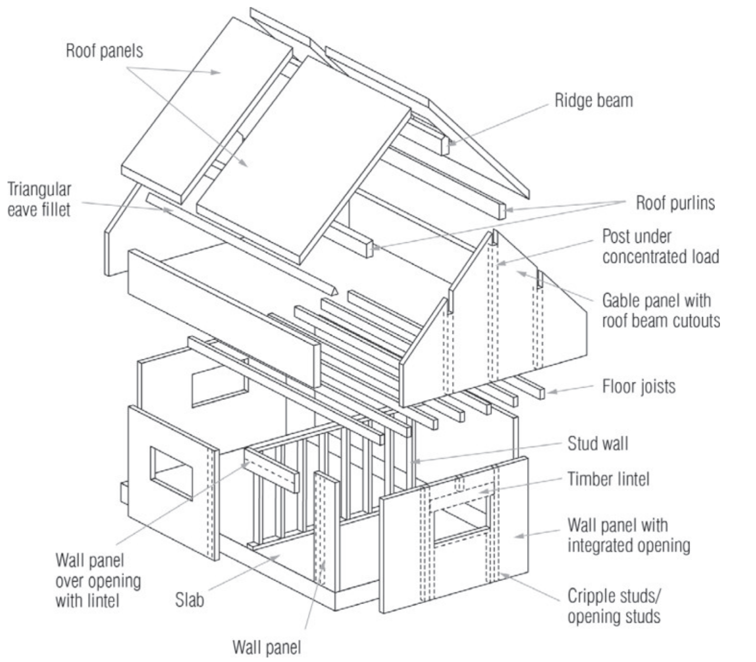

Figure 3
Typical construction of SIP house

Engineering design of SIPs

Transfer of vertical loads

The axial loads on SIPs are transferred through to ground predominantly through the facing material. The foam core keeps the facing sheets aligned and separated. When used as a wall panel under vertical compression, the slender facing material will transfer the load by direct bearing onto the bottom rail, which typically comprises a timber plate or sole plate (Figure 2). Buckling of the facing material is prevented by the foam core which reduces the effective slenderness of the two facing materials/boards. Often, bearing (or a related shear failure) on the bottom rail determines the load-carrying capacity of a wall panel.

Large concentrated loads (e.g. purlins, beam bearings) require groups of timber studs or timber posts to be inserted between the facing boards to provide increased bearing area onto the timber plates and increased axial resistance. These posts are continued down through each level to the foundations to ensure a continuous load path. Timber lintels, cripple studs and opening studs are incorporated around frame openings to provide vertical and horizontal load resistance following standard practice in platform timber frame construction.

Transfer of loads normal to panel

When used in roof applications and for vertical wall elements subjected to wind loading or eccentric fl oor loads, the panel must resist bending moments – primarily by tension and compression of the facing material. The foam core will then transfer shear forces between the two faces. The shear deflections of SIPs are greater than for timber since the foam core has a lower shear modulus; in most cases the shear defl ections dominate. PUR, and to a lesser extent EPS, are susceptible to creep when subjected to sustained stresses. For this reason, SIPs are generally restricted to roof applications where the duration of loading is generally considered to be short-term (flat roofs are acceptable, although careful consideration of condensation control is required). It is possible to use SIPs in floors but the creep eff ects can significantly increase final deflections and there is usually less need to provide thermal insulation between floors. For this reason SIP floor structures are not commonly used. Table 3 and Figure 3 set out the typical use of SIPs in domestic construction.

Strength calculations

The strength evaluation of SIPs typically involves the combination of experimental testing and verifi cation by calculation using composite theory, analogous to the procedures used for thin metallic sandwich panels outlined in BS EN 14509:2013. Since the facing material used in SIPs is generally thicker than in metal-faced sandwich panels, they are less susceptible to wrinkling (local buckling). As there are currently no codes of practice for SIPs, product testing will be required to derive the structural performance of a

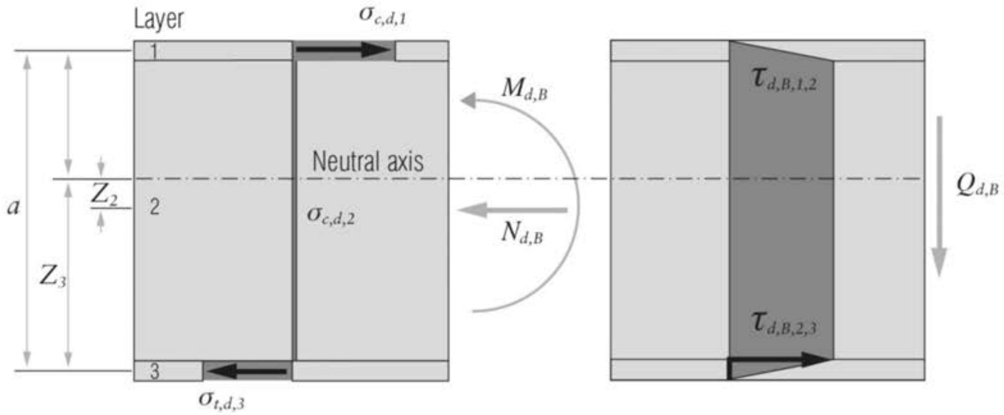

Figure 4
Stress distributions through SIP under axial force and bending moment

Table 1: Advantages and disadvantages of common SIP facing materials

Material	Advantages	Disadvantages
Oriented strand board (OSB)	• Inexpensive • Readily available	• Requires finishing on interior and exterior • Swells with moisture
Cement fibre or magnesium oxide	• Will not rot, burn or corrode • Acts as a finished interior and/or exterior	• Heavier than other options and more difficult to handle • Some products are brittle and prone to cracking during transport • More expensive than OSB

SIP and experimental test methodologies are outlined in European Technical Approval Guideline (ETAG) 019 for Prefabricated wood-based loadbearing stressed skin panels4. (Note that ETAGs are currently being revised and will become European Assessment Documents (EADs).

In addition to ETAG 019, the European Organisation for Technical Assessment (EOTA) has produced a Technical Report (TR019) which outlines Calculation models for prefabricated wood-based loadbearing stressed skin panels for use in roofs. The introduction defines the different possible types of stressed skin panels.

Since SIPs transfer the load primarily through the facing material, they are sometimes referred to as stressed skin panels. However, unreinforced SIPs are not stressed skin panels as defined in BS EN 1995-1-1:2004, Section 9.1.2 for 'Glued thin-flanged beams'6. In the analysis of glued thin-flanged beams, the shear transfer between skins is concentrated around the discrete timber webs (glued joists).

This leads to the concept of an eff ective fl ange width to account for shear lag and flange buckling of the skin. Since the web of a SIP is a continuous foam core, the shear transfer to the skins is uniform and the analysis is therefore different. The term 'sandwich panel' is perhaps a better way to refer to SIPs in order to distinguish them from the common understanding of stressed skin panels. It should be noted that in some roof applications stiffening studs must be incorporated into the SIP to achieve the required spans. In these cases the analysis becomes similar to the analysis for glued thin-flanged beams and the methods for glued thin-flange beams may be used.

The usual method used to determine the strength of SIPs in European assessments is the shear analogy method. This method is applicable to solid panels where the load is applied perpendicular to the panel and takes into account the shear deformation of the core. Figure 4 shows stress distributions in a SIP.

In the shear analogy method, the characteristics of a multi-layer cross-section are separated into two virtual beams, A and B. Beam A is given the sum of the inherent fl exural and shear stiff nesses of the individual laminates along their own centroids, while beam B is given the 'Steiner' stiffnesses, to account for increased moments of area due to their eccentricity from the neutral axis of the section. These two beams are coupled with infinitely rigid web members, so that equal deflections of beam A and B are obtained. By superposition of the bending and shear stresses in both beams, the end result for the combined crosssection is obtained. The governing equations of the shear analogy methods are complex and are not well suited to hand calculations.

Connections

Joints between panels are made using thinner infill SIPs (Figure 5) or solid timber splines secured into rebated edges using mechanical fasteners and sealed using an elastic adhesive or sealant. Rebated wall panel bases slot over pre-fixed timber sole plates and are secured with mechanical fasteners (Figure 6).

Sloping roof panels rest on triangular timber eaves fillets and are secured with mechanical fasteners. Adequate mechanical fasteners must be provided

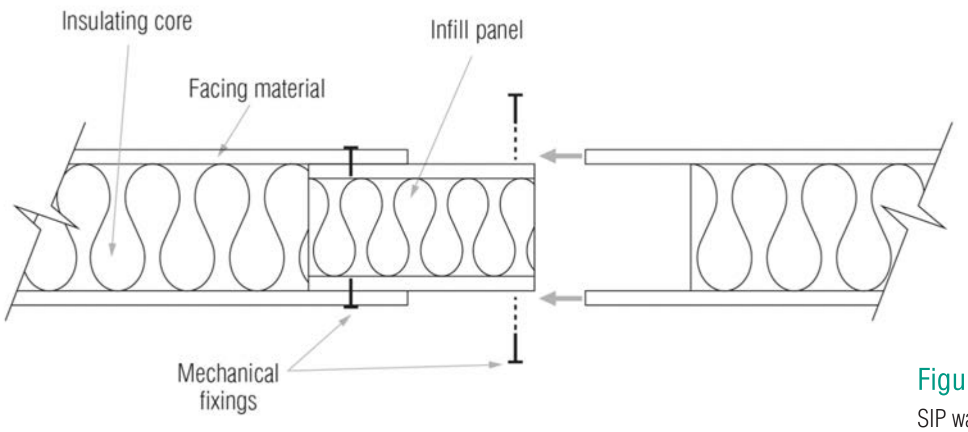

Figure 5
SIP wall connection avoiding thermal bridges

Table 2: Indicative performance characteristics of EPS and PUR insulating foam cores

Material	Bonding agent	Fire performance	Indicative structural properties		Thermal conductivity, λ (W/mK)
			Shear strength (N/mm²)	Shear stiffness (N/mm²)	
PUR	Autohesive	Chars	0.15	4.0	0.023
EPS	Secondary adhesive	Melts (flame retardant treatment is standard)	0.10	3.0	0.033

to prevent the roof sliding down due to the inclined bearings and to provide resistance to wind uplift (Figure 7).

To assess the strength of fixing details to OSB, characteristic material values can be found in BS EN 12369-1:20017 and rules for the strength of connections into OSB can be found in BS EN 1995-1-1:20046.

Edge openings, such as window reveals, incorporate floor-to ceiling studs either side of the opening which support additional framing above and below the opening. With large panels it is possible to incorporate window openings within the panel; the facing material can then span over the opening providing there is sufficient bending capacity in the facing material, or edge reinforcement panels can be designed as a box beam or box lintel. Floors may be sandwiched between upper and lower walls or may be attached to panel inner faces with joist hangers (Figure 8).

Detailed practical guidance and best practice advice on the construction of SIP buildings can be found in the Structural Timber Association's pocket site guide to SIP construction, which includes many example construction details (Figure 9).

Cladding

Any cladding system must provide a rain screen, and a drained ventilated cavity is also typically incorporated. There are two types of cladding systems:

- a free-standing cladding system, such as brickwork or blockwork, requires the SIPs to provide restraint to the masonry via wall ties. The wall tie fixings should be checked to ensure that any tensile loads can be adequately transferred into the OSB skin
- claddings that are structurally supported off the SIP. Typical systems include battens for tiles or for render systems, steel-based sheeting or timber boarding. Strength checks should be carried out to ensure that the weight of the cladding can be adequately transferred through the wall batten fixings into the OSB skin.

Service installation

As with all buildings, preplanning for follow-on trades is essential to avoid delays and remedial work. Services need to be planned in advance so that ducts and conduits are available. In addition, backing timbers may be required to support heavy loads from wall-mounted boilers etc. Plumbers and electricians need to be aware of the system being built so that they do not cut, groove or ignite the panels during installation of their services.

All wiring should be installed in approved conduits, or mounted on the face of the panel behind a plasterboard surface. The common practice in the USA of chasing wires and electrical points into the core of the panel is not recommended since overheating of electrical wires could cause ignition of the inner core.

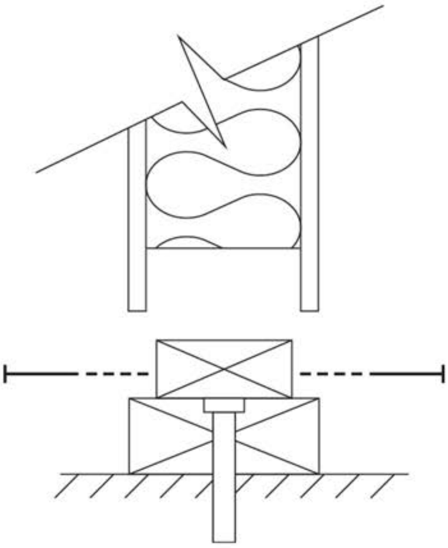

Figure 6

SIP-to-sole plate connection detail

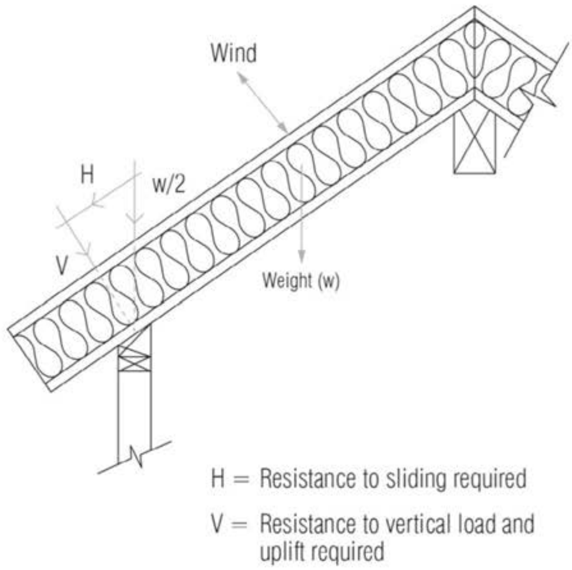

Figure 7

Resistance of SIP roof panel to sliding and wind uplift

Table 3: Use of SIPs in domestic construction

Application	Function
Structural walls	To provide vertical and horizontal strength of the building, as well as providing thermal resistance
Curtain walls	As an insulated cladding panel where the external skin is designed for the appropriate weather protection. Where OSB-faced products are used, secondary weather protection is required
Infill walls	As a prefabricated panel between post and beam structures to provide thermal insulation and wind load transfer
Structural floors	To act as both floor decking and joists to span across supporting walls – not a common application due to the complexity of the support and long-term deflection concerns
Structural roofs	To act as thermal insulation to the top of the main structure
Infill roofs	To act as both roof sarking/deck and rafters to span across supporting walls and purlin, as well as providing insulation

Guidance on allowable hole sizes for new services can be providedby the SIP manufacturers. In general terms, holes up to a maximum diameter of 200mm in panels that have a minimum width of 900mm can be tolerated providing the holes are no closer than 150mm to the end of the panel, or panel junction. Checks should be made with the manufacturer to ensure that there is not a load-bearing stud at the proposed hole location.

Building modifications

The size of openings for doors and windows can be increased, after appraisal of the relevant load paths, by introducing new timbers to frame the openings. The removal of panels may be permitted once an appraisal of the strength of the building is made for stability and vertical loads. However, the modification of a SIP structure should never be undertaken without the guidance of a suitably qualified structural engineer.

Durability

One of the complexities involved with SIP design is that the internal face is likely to be in service class 1 while the outer face will be in service class 2. SIP roofs are to be classified as 'cold roofs', i.e. the outer facing is found outside the insulation zone and is therefore subject to a temperature gradient. SIP roofs, whether pitched or flat, will therefore require a ventilation void between the SIP and the roof covering to avoid the risk of condensation.

Resistance to fungal growth on the surface of the panels is achieved through the design of the ventilation. The potential for fungi to grow in the core is considered negligible providing the panels are designed to avoid condensation build-up in the core.

The insulation cores used do not provide food for insects, fungi or rodents. However, rodents and insects could burrow into the core and nest. This can be avoided through good detailing, such as the use of insect screens, to prevent cavity access.

After delivery to site, panels should be protected from rain before they are placed into their fi nal position. Once installed, intermittent wetting from rain will not normally have an adverse eff ect; however, standing water can create problems. SIPs can be susceptible to moisture uptake during construction. Water traps can occur at each floor level as rain water cannot escape the

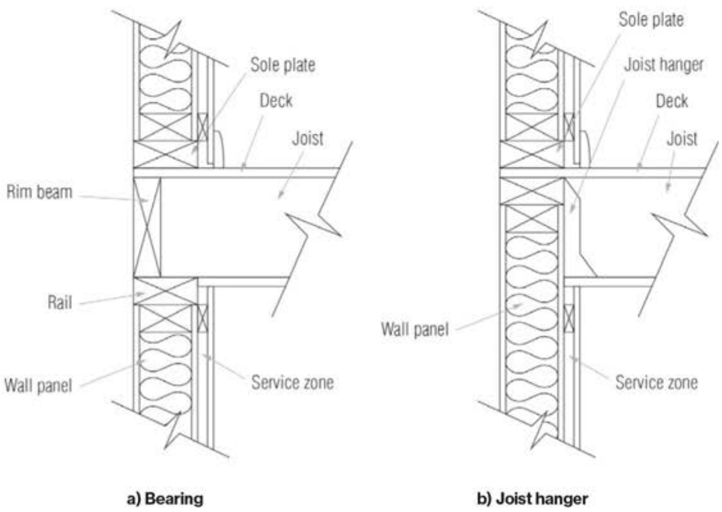

Figure 8
SIP wall-to-floor junctions

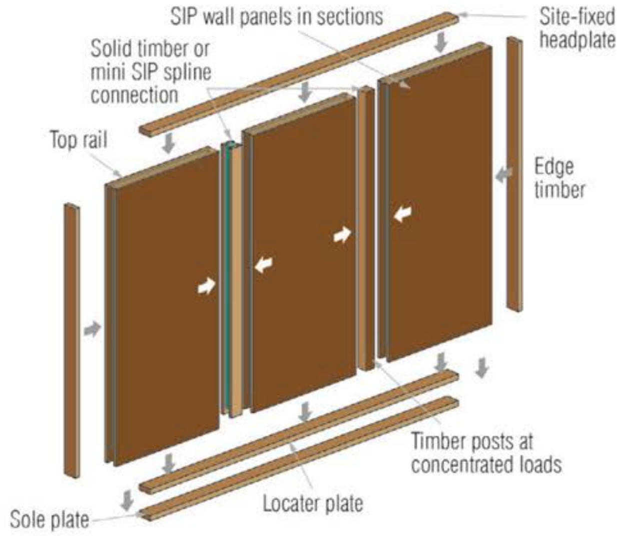

Figure 9
SIP wall frame connection

perimeter. The method of construction used in SIP buildings is such that the timber board is very close to the floor deck and water can wick up through the end grain of the board. Panel edge protection is essential to minimise water at the base of the panels. If a panel does get wet, the board will dry out after heating is applied to the building, but this may impact on the internal finishes or the structural capacity of the panel at the floor junction. If a panel becomes saturated, then replacement or remedial work may be necessary and specialist advice should be sought.

Fire performance

Appendix F in Part B of the Building Regulations provides a description of the issues relating to the fi re behaviour of insulating core panels used for internal structures. The principle concern for load-bearing insulating panels relates to the spread of fire within a panel. The document recommends that a design risk assessment is made and that the potential risk of a fire is “designed out”. The document is focused on commercial and industrial applications where the risk of fi re breaking out is typically higher than within a home and where the fire resistance requirements are consequently higher.

The fire performance of SIP products is typically achieved by the application of plasterboard or other fire-resistant board to the internal facing material. Some manufacturers off er SIPs with factory-fitted fire-resistant boards over the top of or in place of the OSB in order to reduce the construction-stage fire risk. The design of SIP buildings is reliant on the panel-to-panel junctions for fire protection and these must be included in any fi re assessment. Such an approach will provide satisfactory compliance with the Building Regulations.

Specific concerns about the performance of SIPs in fire include:

- smoke production from the core if both the plasterboard lining and the SIP board material are breached
- structural collapse if plasterboard is breached and the structure relies only on the SIPs for strength

As with all building materials, quality of workmanship can determine the fire resistance of a building. Smoke production is a major concern for all building materials. In a domestic building, there is a view that the major release of smoke is from the internal fixtures and fittings, and that in a well-insulated and airtight building, such as a SIP house, a fire will consume the oxygen supply quickly and extinguish itself before damage can occur to the structure.

Environmental considerations

The environmental credentials of SIPs generally come from their ability to create well-insulated, airtight buildings. U-values as low as 0.11W/m²K can be achieved, although particular attention should be made to reducing cold bridges through the rail or sole plate, around windows and through stiff ening columns or studs. PUR has higher insulating properties than EPS, so thinner insulation is needed to achieve the same U-value.

OSB uses tree thinnings as its source material; these are a natural part of forest maintenance and therefore a sustainable product. OSB used in timber framing has an A+ environmental rating according to the BRE Green Guide. Other softwood timber used in SIP construction should be sourced from managed forests.

Since insulation has a very low density, only small masses are needed to produce high levels of insulation. Compared to other components of the building, the total mass of insulation is very low, which makes it one of the smallest contributors to the environmental impact of construction.

According to the BRE Green Guide, EPS insulations achieve A+ ratings, while PUR insulations achieve A ratings. The foam core is usually oil-based and can be recycled at the end of its life, although deconstruction is a better alternative.

The most environmentally friendly method of reusing materials from SIP buildings is deconstruction. SIPs can be cut easily and new joints formed by rebating the foam core. Wall panels with openings can be cut into solid sections and re-jointed to form continuous wall panels within which new openings can be formed. Because there are no discrete structural elements, such as studs, SIPs are much easier to reuse once deconstructed and can off er the same thermal performance as new panels. They are also robust enough to withstand the rigours of deconstruction, unlike other more traditional forms of construction.

RELEVANT CODES OF PRACTICE

BS EN 1990:2002 Eurocode 0: Basis of structural design

BS EN 1995-1-1 Eurocode 5: Design of Timber Structures – Part 1-1: General – Common rules and rules for buildings

BS EN 1995-1-1 UK National Annex to Eurocode 5: Design of Timber Structures – Part 1-1: General – Common rules and rules for buildings

PD6693-1:2012 UK Non-Contradictory Complementary Information (NCCI) to Eurocode 5: Design of timber structures

BS EN 12369-1:2001 Wood-based panels. Characteristic values for structural design. OSB, particleboards and fireboards

DEFINITIONS

OSB – oriented strand board (OSB) is an engineered wood product made from cross-oriented layers of thin, rectangular wooden strips compressed and bonded together with wax and resin adhesives. OSB has been extensively tested as a loadbearing material and is commonly available in large sizes

SIP – structural insulated panels (SIPs) are engineered, load-carrying, timber-based panel products. SIPs are generally made by sandwiching a core of rigid foam insulation between two structural skins

REFERENCES AND FURTHER READING

Structural Timber Association (2013) 'Timber Engineering Notebook No.2: Engineered wood products and an introduction to timber structural systems', The Structural Engineer, 91 (4), pp. 42–48

Structural Timber Association (2013) 'Timber Engineering Notebook Timber frame structures – platform frame construction (part 1)', The Structural Engineer, 91 (5), pp. 26–32

British Standards Institution (2013) BS EN 14509:2013 Selfsupporting double skin metal faced insulating panels. Factory made products. Specifications, London, UK: BSI

European Organisation for Technical Assessment (2004) ETAG 019: Guideline for European Technical Approval for prefabricated wood-based loadbearing stressed skin panels [Online] Available at: www.eota.eu/handlers/download.ashx?fi lename=endorsedetags%5cetag019%2fetag-019-en.pdf (Accessed: June 2015)

European Organisation for Technical Assessment (2005) TR019: Calculation models for prefabricated wood-based loadbearing stressed skin panels for use in roofs [Online] Available at: www.eota.eu/handlers/download.ashx?fi lename=technical-reports%2ftr019total.pdf (Accessed: June 2015)

British Standards Institution (2004) BS EN 1995-1-1:2004 Eurocode 5: Design of Timber Structures. General. Common rules and rules for buildings, London, UK: BSI

British Standards Institution (2001) BS EN 12369-1:2001 Woodbased panels. Characteristic values for structural design. OSB, particleboards and fireboards, London, UK: BSI Structural Timber Association (2015) SIP construction: A useful pocket site guide, Alloa, UK: STA

Lancashire R. and Taylor L. (2014) 'How to design a fl at roof', Timber Industry Yearbook 2014, High Wycombe, UK: TRADA Technology Ltd, pp. 67–71

HM Government (2013) The Building Regulations 2010: Approved Document B – Fire safety: Volume 2 – Buildings other than dwellinghouses, Appendix F [Online] Available at: www.planningportal.gov.uk/uploads/br/BR_PDF_AD_B2_2013.pdf (Accessed: June 2015)

Structural Timber Association (2012) Design guide to separating distances during construction: For timber buildings above 600m2 total floor area [Online] Available at: www.structuraltimber.co.uk/informationcentre/technical-library/site-safe/ (Accessed: June 2015)

BRE (2015) Green Guide to Specifi cation [Online] Available at: www.bre.co.uk/greenguide/podpage.jsp?id=2126 (Accessed: June 2015)

Structural Timber Association (2015)
SIP Construction - A useful pocket site guide