Title	Design for deconstruction and reuse: An Irish suburban semi-detached dwelling
Authors(s)	Walsh, St. John, Shotton, Elizabeth
Publication date	2022-04-01
Publication information	Walsh, St. John, and Elizabeth Shotton. “Design for Deconstruction and Reuse: An Irish Suburban Semi-Detached Dwelling.” School of Architecture, Planning & Environmental Policy, University College Dublin, April 1, 2022.
Publisher	School of Architecture, Planning & Environmental Policy, University College Dublin
Item record/more information	http://hdl.handle.net/10197/13111

Design for deconstruction and reuse: An Irish suburban semi-detached dwelling

St John Walsh[1], Elizabeth Shotton[1]

[1]University College Dublin

Figure 1.1: Typical suburban semi-detached houses, exterior (Cygnum Timber Frame)

April 2022

Innovative Design for the **Fu**ture – **U**se and **Re**use of **Wood** Building Components

ISBN: 978-1-910963-53-1

FOREWORD

This report is one in a series of case study reports in the InFutURe Wood project - Innovative Design for the Future – Use and Reuse of Wood (Building) Components.
InFutUReWood is supported under the umbrella of ERA-NET and financed by funding agencies from each of the participating countries. The industry partners participate mostly with in-kind.
The research and academia project partners are RISE (Sweden), Edinburgh Napier University (UK), National University of Ireland Galway (Ireland), University College Dublin (Ireland), Polytechnic University of Madrid (Spain), University of Ljubljana (Slovenia), Aalto University Helsinki (Finland), and Technical University Munich (Germany).
The industry partners are Kiruna Municipality Technical Service, Swedish Wood, Derome, Isotimber, Offsite Solutions Scotland, Hegarty Demolition, SIP Energy, Connaught Timber, The Federation of the Finnish Woodworking Industries, Jelovica, The Swedish Federation of Wood and Furniture Industry, Balcas Timber, Stora Enso, Klimark + Nova domus Hábitat, and Brenner Planungsgesellschaft.

ForestValue umbrella of ERA-NET Cofund ForestValue by Vinnova – Sweden's Innovation Agency, Formas, Swedish Energy Agency, the Forestry Commissioners for the UK, the Department of Agriculture, Food and the Marine for Ireland, the Ministry of the Environment for Finland, the Federal Ministry of Food and Agriculture through the Agency for Renewable Resources for Germany, the Ministry of Science, Innovation and Universities for Spain, the Ministry of Education, Science and Sport for Slovenia. This is supported under the umbrella of ERA-NET Cofund ForestValue, and ForestValue has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773324

SUMMARY

Background: Residential buildings in Ireland have long been constructed of load-bearing masonry with structural timber use limited to intermediate floor joists and roof structures. The growing phenomenon of timber platform framing in Ireland in the last 30 years has increased the share of this construction type to a current 27% of residential new builds primarily using prefabricated wall and floor panels. Despite this surge of interest in timber construction, recovered timber in Ireland is typically downcycling into wood chip-based products or for energy.

Aims and objectives: Given Ireland's limited structural-grade timber stock, the ever-increasing share of timber use in residential construction will eventually put considerable pressure on timber supplies. The aim of this study was to evaluate a typical Irish semidetached house design, prefabricated by Cygnum Timber Frame, to identify the potential for reuse of primary material components in the current design and improve the recovery rate in a new design modified on the principles of Designing for Adaptability (DfA), to extend the service life of the building, and Designing for Disassembly and Reuse (DfDR) to maximise recapture and reuse potential.

Methods: Although the Cygnum design is constructed of prefabricated 2D wall and floor panels, so could have been analysed under a scenario of reusing these panels as other case studies did (UK, Sweden) our analysis considered the disassembly process from the perspective of the ultimate end-of-service life of the panels when they would be disassembled into material components. The construction system was analysed for how it would be disassembled, and the recovery rate of material calculated; any obstacles to disassembly were identified, which informed the new design proposal; and a similar assessment of recovery rates made for the new proposal. The modified design was compared to the original Cygnum design, both using a ground floor concrete slab, which was then altered to a timber-framed suspended ground floor assembly to assess the impact of this change.

Results: The original Cygnum design used I-joists with a glued and nailed subfloor, which was deemed unrecoverable as were all OSB sheathing. The recovery rate for solid timber elements greater than 1m, deemed the shortest length that would be reusable, was 41% of all timber material, while high value lengths greater than 2.35m were recaptured at a rate of 32.7% of solid timber (18.1% of all timber). In the modified design, which rationalised timber framing and made strategic use of wood nails and screws rather than nails, the recovery rate for solid timber elements greater than 1m was 60.1% of all timber material, while lengths greater than 2.35m were recaptured at a rate of 74% of solid timber (53% of all timber). When modified to include a timber framed ground floor these recovery rates increased to 62.5% solid timber over 1m to all timber material and 78% of all solid timber over 2.35m (56% of all timber).

Conclusions: Very limited interventions in the design including the strategic use of wood nails and screws, coupled with a rationalisation of the framing to minimise construction waste and the use of solid wood joists over I-joists, served to make the design far easier to disassemble with a view to maximising high-value timber for reuse.

TABLE OF CONTENTS

1 Introduction

1.1 Background

The building sector accounts for a large contribution of society's Green House Gas emissions, raw material consumption and waste production. One way of diminishing this environmental impact would be to reuse buildings and building components to a higher degree.

The circular economy considers materials and products after-use value as important environmental and economic factors and a key tool to reduce global warming (Foundation, 2013). As such, buildings may be considered as material banks, as repositories for materials that could potentially be extracted for reuse or re purposing in the future (Debacker et al., 2016). As these building elements begin to replace primary resources extracted for construction, the need for primary resource use is reduced. Yet in Ireland, timber is largely considered a single use product in a linear economy (Figure 1.2 and 1.3), with considerable amounts of material incinerated for energy following demolition (Figure 1.4) and thus increasing the emission of carbon into the atmosphere (Llana et al., 2020).

Figure 1.2 and 1.3: Mixed skip with significant timber content and (1.3) wood waste before processing at Thornton Recycling facilities (Walsh, n.d.)

The percentage of housing constructed with timber frame in Ireland has increased significantly over the past two decades. Prior to 1990, less than 1% of annual residential construction was undertaken using timber frame; however, by 2002, timber frame housing accounted for approximately 15% of the annual Irish housing output in Ireland (TFHC). This increased to almost 25% by 2004. In 2019, 5500 houses were built using timber frames (ITFMA, 2020) which represents 27% of Irish new houses (CSO, 2020).

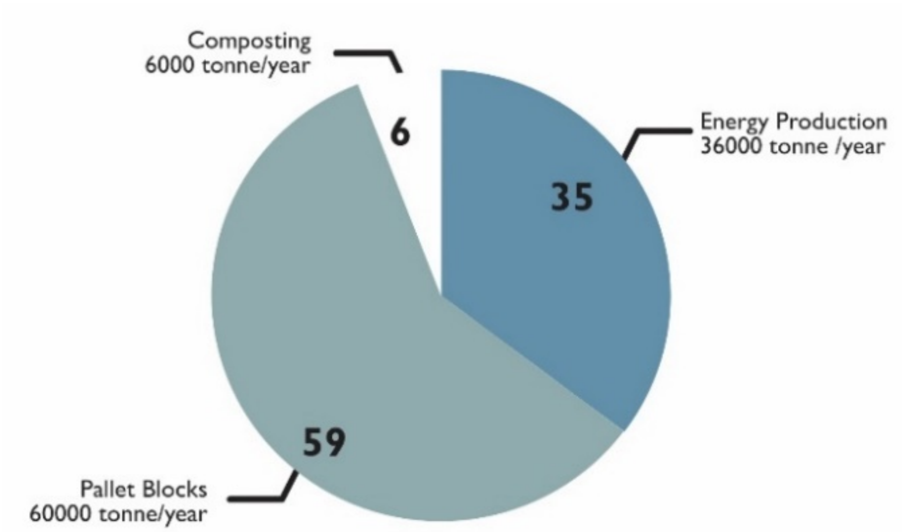


Figure 1.4: Amount of Wood Waste in Ireland per Annum & End Use (Llana et al., 2020)

The InFutUReWood project is studying how to establish circularity for timber buildings. There is a lack of published knowledge on how wood-based building frames are best designed for deconstruction and reuse. In Work Package 2, "Design of timber structures for the future", new ways to design timber-based structures are investigated. New design concepts are developed as well as a model to plan primary design to facilitate deconstruction rather than demolition.

1.2 Aim

The aim of this study is to show how timber structures could be designed to be adapted for deconstruction and reuse. The study is one in a series that consider different types of timber-based structures.

This case study concerns a building design from the Irish manufacturer, Cygnum Timber Frame (Figure 1.1). The building consists of a pair of two-storey platform frame semi-detached houses largely constructed offsite as 2D panels. External wall panels are load bearing timber with a non-loading bearing brick outer leaf. Internal load bearing timber walls are found at ground floor only. OSB boards provide racking resistance to walls and floors. Service cavities are formed with timber battens on the walls and ceilings. The floor structure is formed with I-Joists with OSB subflooring. The roof is constructed of prefabricated timber roof trusses. The current timber volume encapsulated is approximately 15.1 m^3.

Much construction is not undertaken at an industrial scale but in fact, at a smaller domestic scale or as one-off constructions. Rather than the industrialized off-site construction method of the existing structure, our case study will aim to examine this structure when considered as an onsite stick-build construction. The rationale for this is to provide more diversity in the case studies in the report, as both Sweden and the UK were examining similar prefabricated 2D panel systems. The ambition was to provide a counterpoint, where prefabricated systems could be compared to onsite framing systems (Figure 1.5). In doing so, we hope to address the opportunities and challenges that face this part of the timber construction industry in implementing circular economy principles.

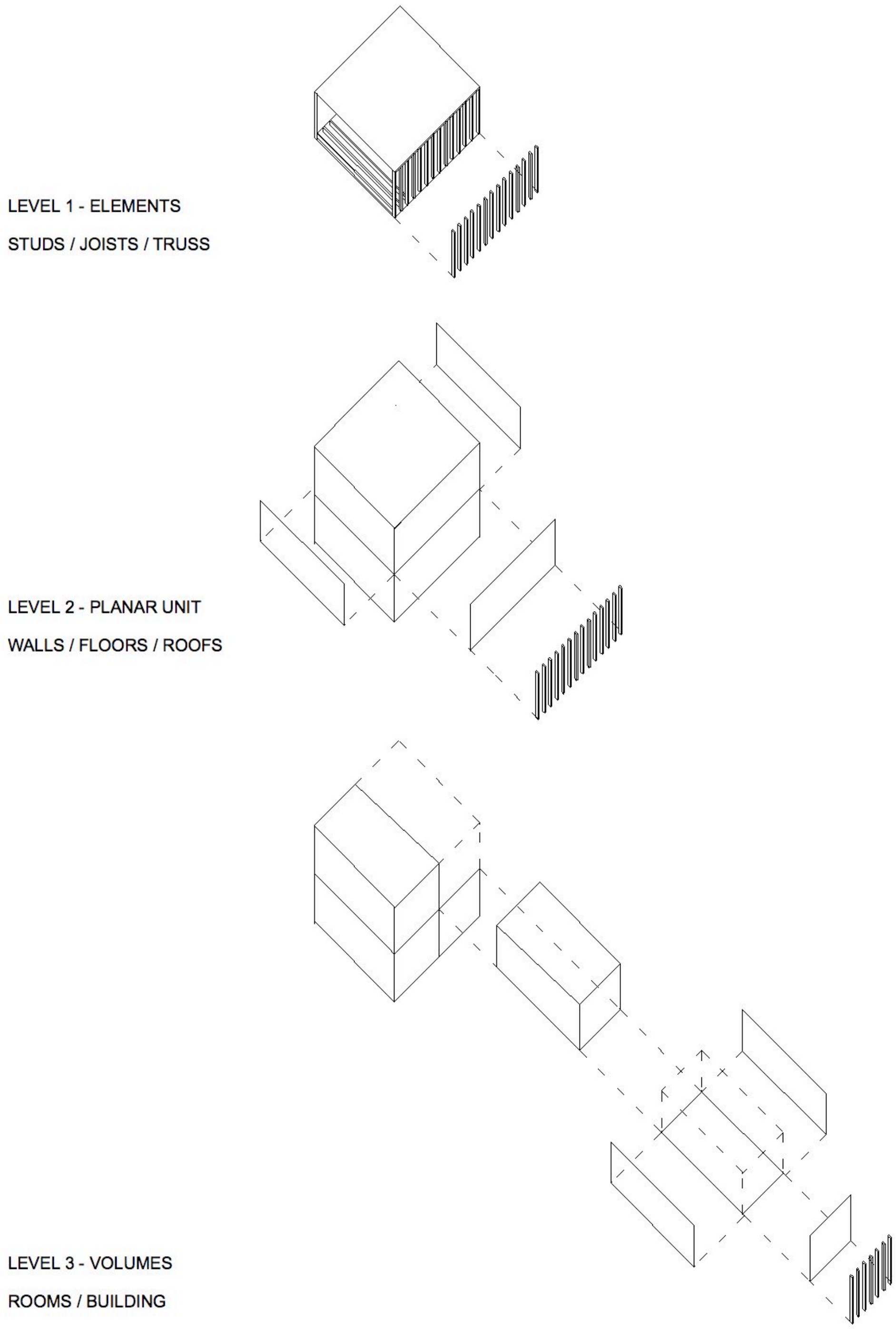


Figure 1.5: Different levels of Timber construction (top: timber frame, middle: panel system, bottom: volumetric system) (Walsh & Sandin, 2020)

Based on a more adaptable layout, the redesigned onsite construction is anticipated to have a longer lifespan, with the intention that the building would be disassembled into individual timber elements at the end of its service life through careful consideration of joints and connections (Figure 1.6). To maximize potential reuse, these elements are kept as close to their original factory sizes as possible.

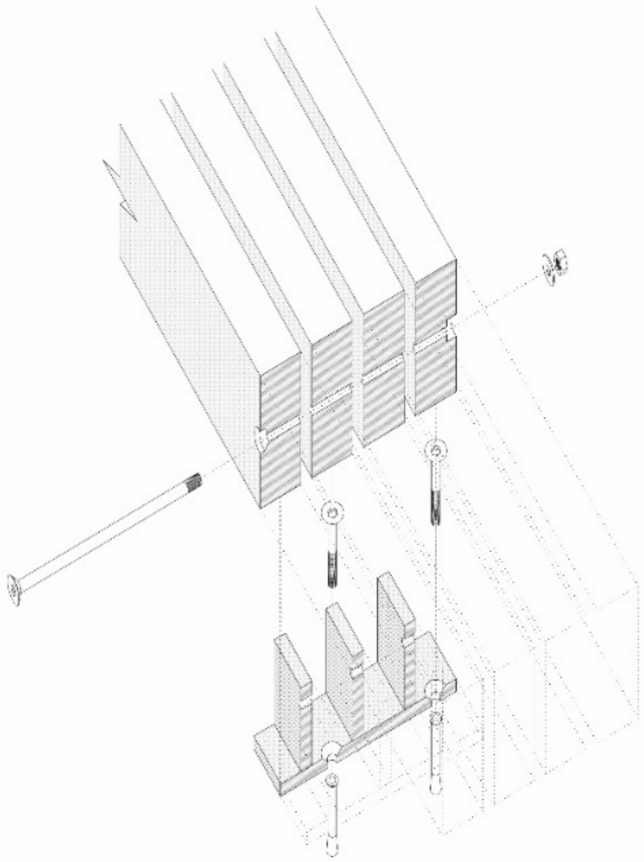


Figure 1.6: Example of Design for Disassembly (DfD) connections (AY Architects)

1.3 Objective

The objective of the case study is to identify:

- What advantages of the current prefabricated design has regarding future deconstruction and reuse.
- What disadvantages the current prefabricated design has regarding future deconstruction and reuse.
- Whether recovery and reuse are improved on a hypothetical onsite light timber frame construction of a similar configuration, and the reasons for this.
- How the spatial design and its constructive details could be improved to maximise future recovery of materials and their reuse in the onsite construction scenario.
- The magnitude of the improvement gained by modifying the design spatially and in terms of construction detail. We will estimate how much wood that could be reused (as opposed to

recycled) in the future from the current design and how much wood that could be reused after these design modifications. Reuse means that a part / component is used for basically the same purpose as it was originally intended. (See also 1.5 Terms and Definitions)

- What the appropriate form a plan for deconstruction and reuse should be for a building of this type.

1.4 Limitations

The focus of this case study will be on the design of the load-bearing structure, the timber frame and associated panels used for lateral stability. Future analysis is required regarding the potential for reuse of non-load bearing elements in the structure.

Over time, as the requirement for insulation has increased, the typical stud depth has also increased (90 mm to 140 mm). The structural depth for walls in the case study is taken as 140 mm however, some construction may still be undertaken using 90 mm studs.

As mentioned above, the current design of the house is a platform framed structure using prefabricated 2D panels. As other case studies are looking at this construction method, our analysis will consider this as an onsite stick-built platform frame construction. This method will be relevant to non-industrialised construction, which could include domestic extensions, one-off dwellings, and non-residential buildings, thus offering increased scope to its relevance to practitioners. As such, we do not envisage that the panels will be reused in our analysis of the current prefabricated assembly. Instead, components are envisioned to be disassembled at the end of use into their constituent parts i.e., stud, rail, sheet. These elements may be reused for the same purpose.

The case study is also not limited to the future reuse of the structural elements, but also rethinks the design by making it more adaptable during the first use phase to extend its potential service life. Thus, the current study encompasses both Design for Disassembly and Reuse (DfDR) as well as Design for Adaptability (DfA).

1.5 Target group

The target group considered for this report are manufacturers of timber-based building structures, architects and engineers and researchers.

1.6 Terms and definitions

Design for Adaptability (DfA)

Ability to be changed or modified to make suitable for a particular purpose. (ISO 6707-1:2017, 3.7.3.79)

Deconstruction

The process of taking a building or structure, or portion thereof, apart with the intent of repurposing, reusing, recycling, or salvaging as many of the materials, products, components, assemblies, or modules as possible. (Off-Site Construction Council)

The systematic dismantling and removal of a structure or its parts, in the reverse order of construction, for maximum value through the salvage and harvest of components, primarily for reuse in their original purpose and secondarily for recycling. (Ellen Macarthur Foundation 2019)

Disassembly

Non-destructive taking apart of an assembled product into constituent materials and/or components (BS 8001 2017, ISO 8887-2 2009.)

Reuse

Any operation by which products or components that are not waste are used again for the same purpose for which they were conceived. (EC 2008)

Recycling

Any recovery operation by which waste materials are reprocessed into products, materials, or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations. (EC 2008)

Ground floor and first floor

We adhere to traditions large parts of Europe to call the floor on the ground the ground floor and the next floor up the first floor.

Improvement, improved solution

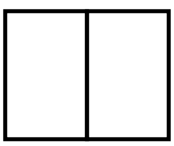
By improvement is understood a measure that leads to components retaining their functions and economic value to a greater degree in a future deconstruction process or leads to a less time-consuming or safer deconstruction process than can be reached with the current design. With improvements fewer damages will occur, less repair/ reconditioning will be required for the next use cycle, a larger proportion of the material can be reused, less time will be needed for deconstruction.

Party Wall

A wall shared between two houses, found in semi-detached or terraced housing.

Semi-detached

A semi-detached house shares one wall with another house.



2 Case study method

As noted above, this case study is one in a series, where all cases are carried out using a common method. This chapter presents the case study method. After an overview of the different steps, the separate steps and their implementation are explained.

2.1 Overview of steps

The method developed for this study has five steps, see Figure 2. The different steps are described in sections 2.2 – 2.6.

Step 0. Defining a scenario to design for

Step 1. Analysis of existing design

1.1 Description of the building and how it is assembled

1.2 Simulation of deconstruction and reassembly as well as identification of strengths and weaknesses

1.3 Identification of areas to improve

1.4 Selection of areas to improve

1.5 Calculation of the amount of wood that can be reused with today's design

Step 2. Modified design

Step 3. Comparison existing - modified design

Figure 2.1: The steps of the case study method (Sandin et al., 2021)

2.2 Step 0. Definition of scenario to design for

The future scenario that the design was evaluated and adapted for was defined as follows:
After one service life (about fifty years), the building will be deconstructed into its original elements (studs, sheets, battens etc.), transported to a merchant or another facility and reused in construction. This scenario results in a greater flexibility in how the recovered material is used as it is not so limited by local design factors or the original design.

2.3 Step 1: Analysis of existing design

Step 1.1: Information was collected from drawings, pictures, and interviews from Cygnum Timber Frame, including: building type, parts, connections, presence of chemicals, mechanical and electrical services and their connection to the load bearing structure and the assembly process. Based on the supplier's drawings from Cygnum Timber Frame, descriptions and discussions with the manufacturer, a description was made of the building system and how it is assembled in its original/first phase. The main steps in an assumed deconstruction process were also defined based on the knowledge that existed about the system and how it is assembled.

Step 1.2: This step, as well as Step 1.3, was carried out in a meeting with the UCD research group and an industry representative from Cygnum. The main steps in an assumed deconstruction process were first identified, based on knowledge of the system and how it is assembled the first time.

UCD research team discussed the assumed deconstruction process in detail, drawing on their experience as architects, with input from Cygnum engineers. The advantages and disadvantages of the existing design regarding deconstruction and reuse were identified. Aspects of the deconstruction process that were considered included:

- tools needed for deconstruction
- damage that may occur to components and materials during deconstruction
- need for reconditioning, repair, and controls
- foreseen waste
- risks regarding personal safety

Step 1.3: Areas for improvement were identified in current prefabricated system and were used to inform the hypothetical redesign as an onsite construction.

Step 1.4: Based on the possible areas for improvement, a choice of the most practical improvements were identified based on current Irish construction practice. Choices were based on meetings with UCD researchers with occasional input from Cygnum. Research was undertaken in alternative connection systems. As full-scale or lab-scale testing of connections [for time, ease of assembly and disassembly, and structural tests) was not possible due to the Covid-19 pandemic, assumptions regarding the ease of assembly or disassembly were made based on practical site experience of the researchers (both architects with professional experience) in addition to some input, specifically in the case of wood nails, from the manufacturer (Lignoloc) and a joinery firm that had used these systems (Cascade Joinery). Structural testing data for wood nails is available from Lignoloc.

Step 1.5: An estimation was made of the amount of wood that would go to waste if the current prefabricated design was to be completely deconstructed and the material (rather than the panels) reused. The amount of wood in the load bearing structure of the current prefabricated assembly was provided by Cygnum and confirmed with a BIM model created by UCD researchers. The amount of wood that that could be recovered for reuse (not recycling) was estimated by UCD researchers based on the following assumptions:

- Solid timber under 1m would not be reused
- OSB panels would not be recovered undamaged, so should be used for energy generation or other use
- I-Joists would not be reused after recovery (based on Cygnum guidance) so would be recycled or downcycled for energy generation
- Nails would not be removed easily, so would result in the ends of structural members being cut off

These assumptions, which differ from case studies that assumed the reuse of entire panel assemblies, had an impact on the recovery rate for both the existing design as well as the proposed design to be constructed onsite.

2.4 Step 2. Modified design

The existing design has been examined and modified to address weaknesses in the original design, when considered for deconstruction into individual timber members.

- Redesign of the building layout and construction to increase longevity of the building use through adaptability (DfA) and flexibility
- Redesign of the building layout and construction to improve efficiency of wood use, minimize onsite waste during construction and improving reusability of elements at end-of-life
- Evaluating potential for reuse using Eurocodes to examine different connection types
- Use of a 3D Development of a BIM model to establish benefits of changes, and provide a baseline for a disassembly inventory/plan

The amount of wood that can be reused with the new design concept is calculated in the same way as for the original design.

2.5 Step 3. Comparison existing - modified design

A comparison is made of the amount of wood easily accessible and reusable for the original design and the new design. Calculation procedure for both existing and modified design:

A. The amount of timber in the building in m3 (A) is calculated.

B. A description is made of causes for parts being damaged (or for some other reason not being reused) (according to assumptions in Step 1.5 above).

C. An estimation is made of the amount of timber withheld from reuse (B).

D. The amount of timber made available for reuse (C) is calculated: C = A - B, or "Reusable amount of timber" = "The amount of timber" - "The amount of wood that is currently withheld from reuse".

Comparisons are made between total timber in each design, the amount of total timber estimated to be recovered and the total timber greater than 2.35m in length that is recovered. This length was chosen it allows for use as a stud in a wall panel achieving at least 2400 mm floor to ceiling height once top and bottom rails are included, thus timber of this length or greater has the best reuse potential.

2.6 Step 4. Reuse documentation that can be linked to BIM

A structure for a deconstruction and reuse documentation for the improved design is developed, building on previous work by Morgan & Stevenson (2005), connected to BIM documentation of materials and products in the building.

3 RESULTS

3.1 Description of the current design

The object of the case study is a prefabricated semi-detached timber frame house by Cygnum (123.5m2 per house or 247m2 for both houses). Established in 1996 Cygnum is one of the leading manufacturers of timber frame solutions and engineered timber structures in the UK and Ireland.

The two houses, which share a common part wall, are arranged over two floors. The living room, kitchen, utility, and toilet are located at ground floor level while at first floor, three bedrooms, a family bathroom, wardrobe, and general storage are located (Figure 3.1).

Figure 3.1: Ground Floor (left) and First Floor plans of semi-detached houses (blue highlights water and plumbing) (Cygnum)

The house is entered from the front and an entrance hall runs along the side wall of the house to provide access to the ground floor accommodation and stairway. The living room is positioned towards the street with the kitchen / dining space opening to the garden at the rear. A small toilet opens off the entrance hallway. The high proportion of the ground floor plan, almost 25%, given over to circulation (hallway and stair) is noteworthy.

The walls at first floor level do not match the layout at ground floor. The primary wall of the bathroom at first floor is located over the likely position of the kitchen and therefore service runs are rationalised here. It does however result in the ground floor toilet being misaligned.

The span of the roof trusses as well as the principal I-Joists run from front to back, making the front and rear walls the principal loadbearing walls.

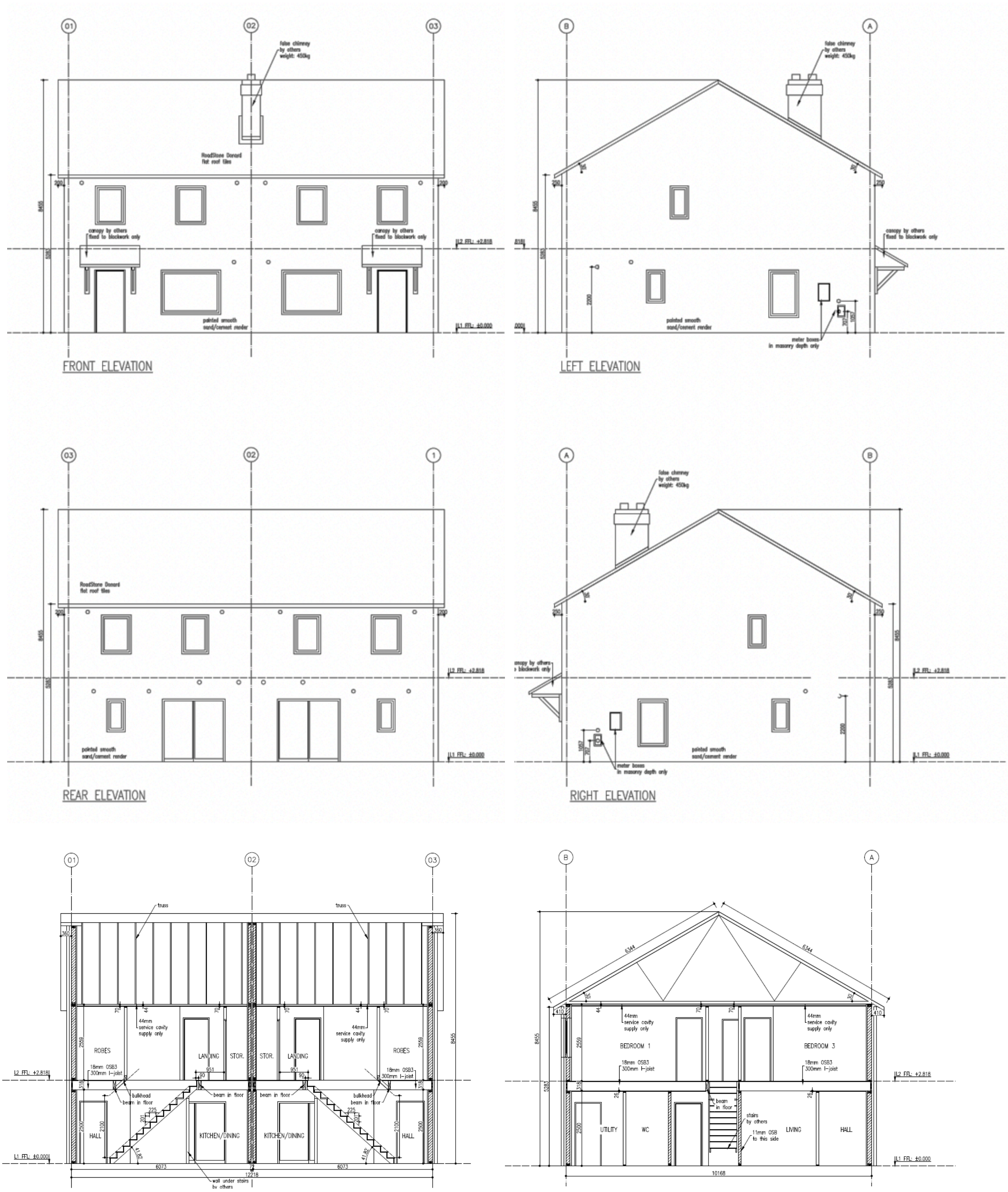


Figure 3.2: Elevations Front and Rear (top left), Side (top right) and Sections (bottom) (Cygnum)

3.1.1 Parts and joints

Elements in load bearing structure

The external wall panels are load bearing, transferring the load of the roof and intermediate floor to the foundations. Internally there are several loadbearing walls at ground floor, which run parallel to the front wall, that provide further support for the first-floor joists and bracing, in addition to the double framed party wall to runs from the concrete on grade to the underside of the roof. The internal walls, largely located in the centre of the plan, are arranged to allow for trimming joists around the staircase. The engineered roof truss structure spans from the front to the rear walls and there are no load bearing internal walls at first floor level. Oriented Strand boards (OSB3) are fixed to walls and joists to provide racking resistance

All exterior walls panels, I-joist floor panels and roof trusses are delivered to the building site as prefabricated elements. The external wall elements are supplied as enclosed units with the insulation and vapour control layer fitted in advance. The truss elements are typically provided by a sub-contractor of the manufacturer, and therefore have limited off site fitting undertaken prior to installation. The building is completed on site with internal and external finishes. The parts that form the building's load bearing structure (Figure 3.3) are, from top to bottom:

- **Roofing** is composed of slates nailed to battens that are nailed to roof trusses below, which transfer wind and snow loading to the roof truss below
- **Roof trusses** are fabricated from small section structural timber and nail plates. The tie beams of truss form the ceiling structure of first floor, with battens forming a service cavity.
- **Exterior gable wall panels** (see exterior walls first floor, no service cavity)
- **Party Walls within roof space** (see party walls first floor)
- **Exterior walls on first floor** are composite wall panel elements which include 38 x 140 mm studs, insulation, vapour control layer and OSB3 facings. A service cavity is also fitted to the panels. OSB Sheathing boards act against racking of these frames (see Panel Composition).
- **Party Walls on first floor** are both structural and fire resisting. These are double 38 x 89mm stud walls clad with OSB3 on each side of the frame. These elements come pre-clad with plasterboard to ensure their fire integrity (see Panel Composition).
- **First-floor panels** built of I-joists and sheathed in OSB3. There is no service cavity at ground floor ceiling level (see Panel Composition).
- **Exterior walls on ground floor** (see exterior walls first floor)
- **Party Walls on ground floor** (see party walls first floor)
- **Interior loadbearing walls on ground floor** composed of 38 x 89mm timber frame elements and fitted with OSB3 on one side, with the other completed on site once fixed in place and services run as necessary (see Panel Composition).
- **Concrete foundation walls** and in-situ concrete slab at ground floor, with blockwork walls.

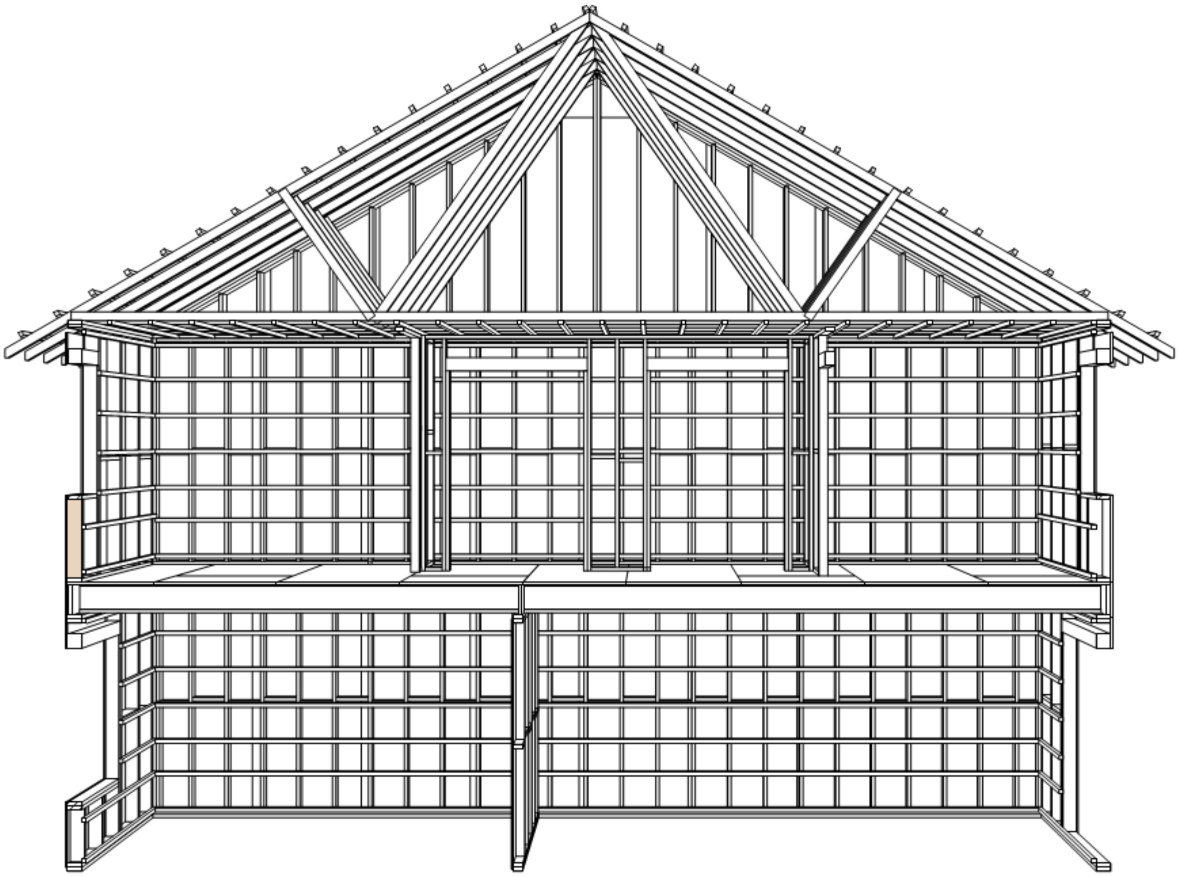


Figure 3.3: BIM model of existing Cygnum semi-detached house timber framing (Walsh 2021)

The cast-in-situ concrete and masonry units that form the foundation and ground floor slab act as a base to which the prefabricated elements are anchored. A timber sole plate is anchored at the centre line of the exterior wall upstand to which the prefabricated timber wall panels are nailed (Figure 3.4). The lower upstand is sized to receive the on-site brick façade which is tied back to the wall panels. The interior load bearing wall details have a similar upstand connection (Figure 3.5).

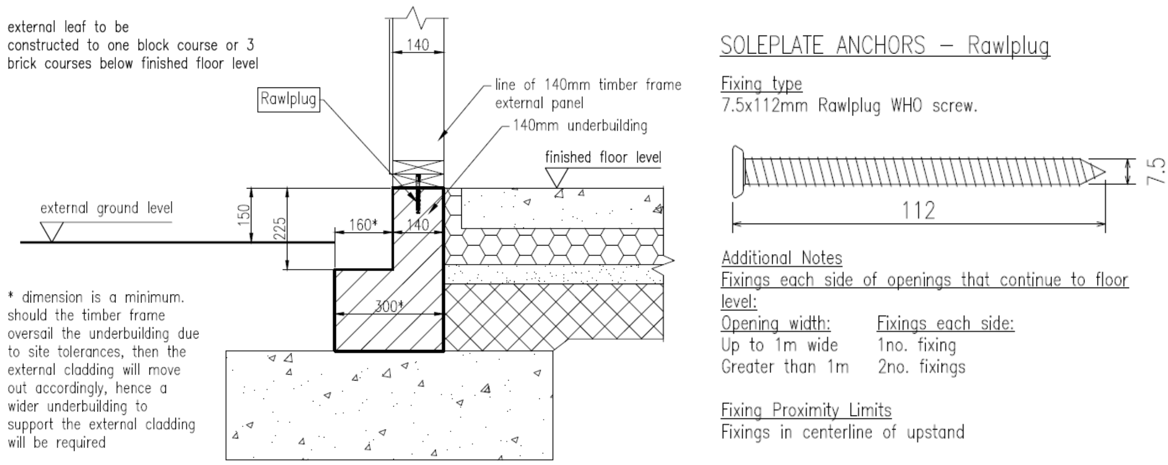


Figure 3.4: Exterior Wall foundation detail with sole plate (left), soleplate anchor (right) (Cygnum)

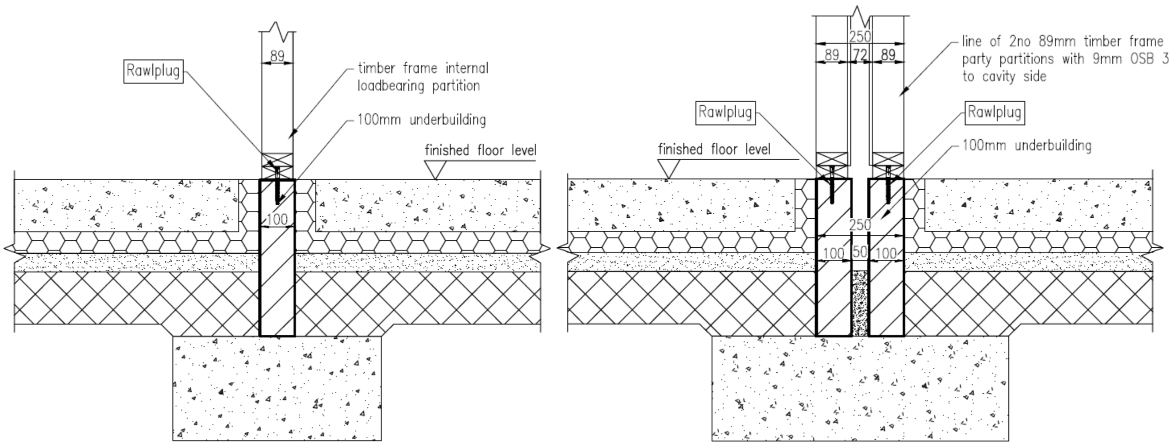


Figure 3.5: Internal ground floor loadbearing wall (left) and party wall (right) (Cygnum)

Panel Composition

Items supplied by Cygnum Timber Frame are listed in the following table and are primarily load bearing prefabricated planar elements. Though most components are fabricated off-site, certain items, such as foundation works, internal finishes, external finishes including walls and roofing, and acoustic insulation are fitted on-site.

Table 3.1 Overview of panel assemblies

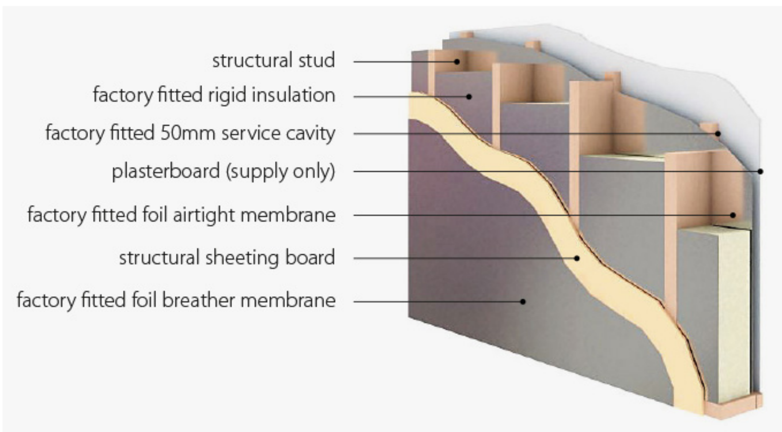
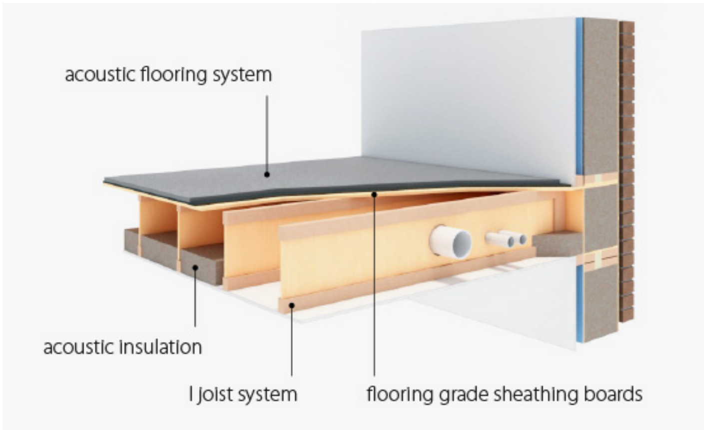
<table>
<tr><th></th><th>-</th></tr>
<tr><td>External Wall Panels</td><td>
- TF200 Thermo
- 9mm OSB3
- 38x140mm c16 timber frame
- 90mm PIR insulation (factory fitted)
- Foil Airtight membrane (factory fitted)
- 44 x 46mm Service Cavity (Factory Fitted)
- Airtight tapes and mastic Gerband (Supply & Site fit)


Figure 3.6: Typical External Stud Wall Panel (Cygnum)
</td></tr>
</table>

Internal Wall Panels (loadbearing and non-loadbearing)	- 38x89mm C16 timber frame - 11mm OSB to racking walls on one or both sides; supplied with one side fitted for installation and services / insulation. - 100mm Acoustic Insulation (supply only)
Party Walls	- 9mm OSB3 to cavity side of each frame - Twin leaf 38x89mm C16 timber frames with cavity between - 100mm acoustic insulation (factory fit) - 15mm Plain (A) and 15mm fire (F) plasterboard (factory fit)
Party wall Spandrels	- 9mm OSB3 to cavity side of each frame - Twin leaf 38 x 89 C16 timber frames with cavity between - 80mm Rigid PIR to bottom 400mm (factory fit) - 15mm Plan (A) and 15mm fire (F) plasterboard (factory fit)
First floor panels	- 18mm OSB3 - 300mm I-Joists - 100mm Acoustic Insulation (Supply only) - FCM 750 airtight membrane for floor wall junctions (factory fit)  ***Figure 3.7: Typical Floor Panel (Cygnum)***
Trussed Roof	- Tiling battens (site fit) - Roofing felt breather membrane (site fit) - Prefabricated roof trusses with timber infill as required - 400mm thermal insulation (supply only) - Vapour control foil (supply only) - 44x64mm service cavity (supply only)

Joints

The typical connection techniques used are screwed and nailed connections. The following table provides an overview of the joints and the manner of their connections, followed by a detailed description of key joints and connections. Details in bold will be discussed at further length below.

Table 3.2 Overview of joints and joint techniques

Part	Junction	Connection / Fixing
Roof Battens	Battens / Truss	Nailed
Roof Trusses	**Fink Truss Members**	**Mending Plates**
Eaves Junction	**Truss / Wall Plate**	**Nailed Truss Clip**
Ceiling Service Cavity	Battens / Ceiling Ties	Nailed
Party Walls	Spandrel / Party Wall	Screwed
Rising Wall Connection	Wall Plate / Concrete rising wall	72.5x112mm Rawlplug Screw
External Wall Panels	**OSB / Stud Frame**	**Nailed**
External Wall Panels	**Wall plate**	**Nailed**
External Wall Panels	**Panel to Panel**	**Nailed**
Interior Load Bearing Walls	OSB / Stud Frame	Nailed
Interior Non-Load Bearing walls	OSB / Stud Frame	Nailed
First Floor I Joists	Noggins / Walls	Nailed
First Floor I Joists	**OSB Subfloor**	**Glued and nailed**

Detail 1: Roof / Truss (Eaves) Junction & Truss Member Connection

The roof structure is composed of timber framed Fink trusses manufactured off site and craned into place on site at 400mm on centre. The configuration of Fink trusses does not allow for inhabitation of the roof space without significant structural modifications. The small section (38 x 89mm) timber members are aligned in-plane and are connected using mending plates. Nailed truss clips connect each roof truss to the head binder of the external walls, while bracing is nailed across the trusses to provide lateral stability (Figure 3.8).

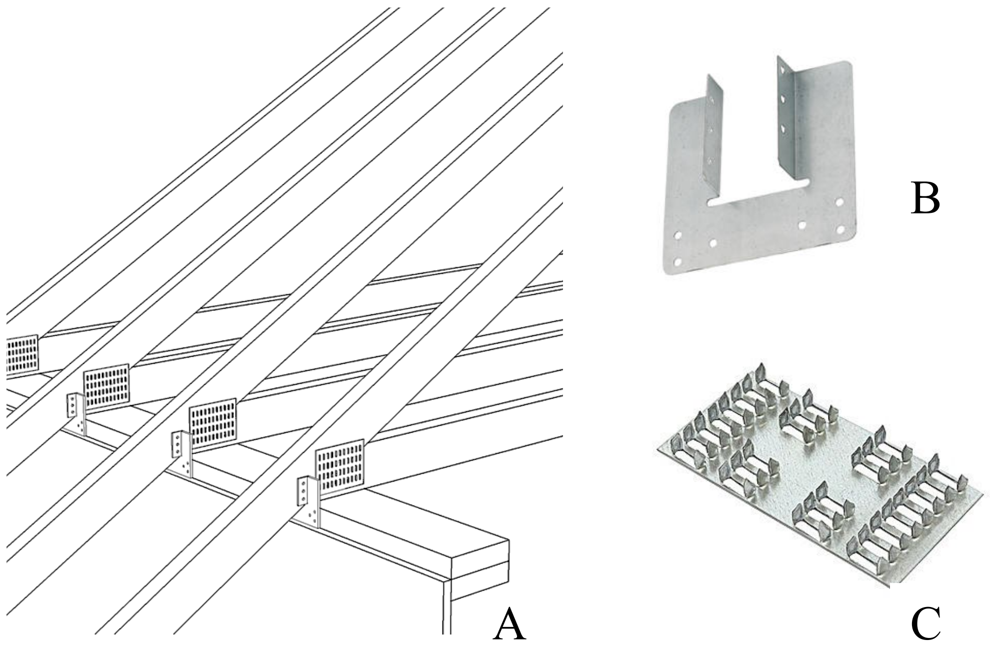
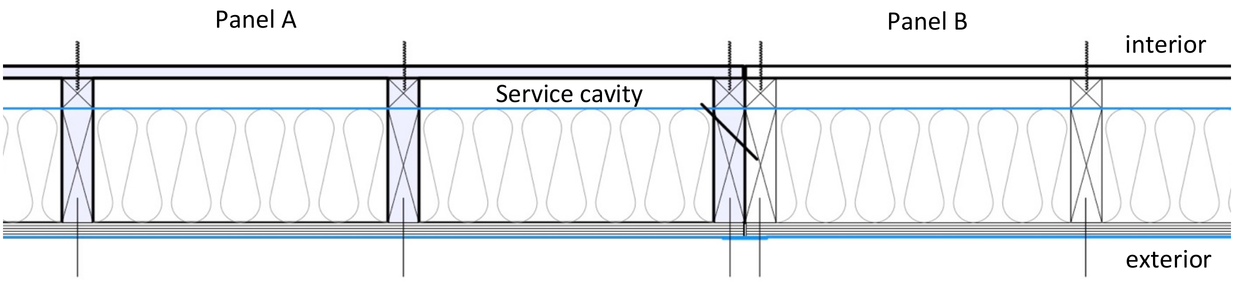


Figure 3.8: Truss connection detail to head binder (A) with nailed connector plate (B). Truss members connected with mending plates (C)

Detail 3: Wall Panel Vertical Junction

The bottom rail of panels is connected to sole plate with nails at a minimum of one per stud bay. An additional fixing is required either side of a window opening greater than 2 m wide. Panel to panel connections are toe-nailed at maximum 300 mm centres vertically, then sealed with tape (Figure



3.9).

Figure 3.9: Wall panel to panel connection (blue are membranes)

Detail 4: External Leaf / Internal Leaf (Wall Tie)

Metal wall tie straps are used to connect the external timber frame wall panels and the outer masonry leaf. These are securely fixed to timber studs and header joists at specified centres. The ends of the stainless-steel wall ties are fully embedded in the mortar joints (Figure 3.10).

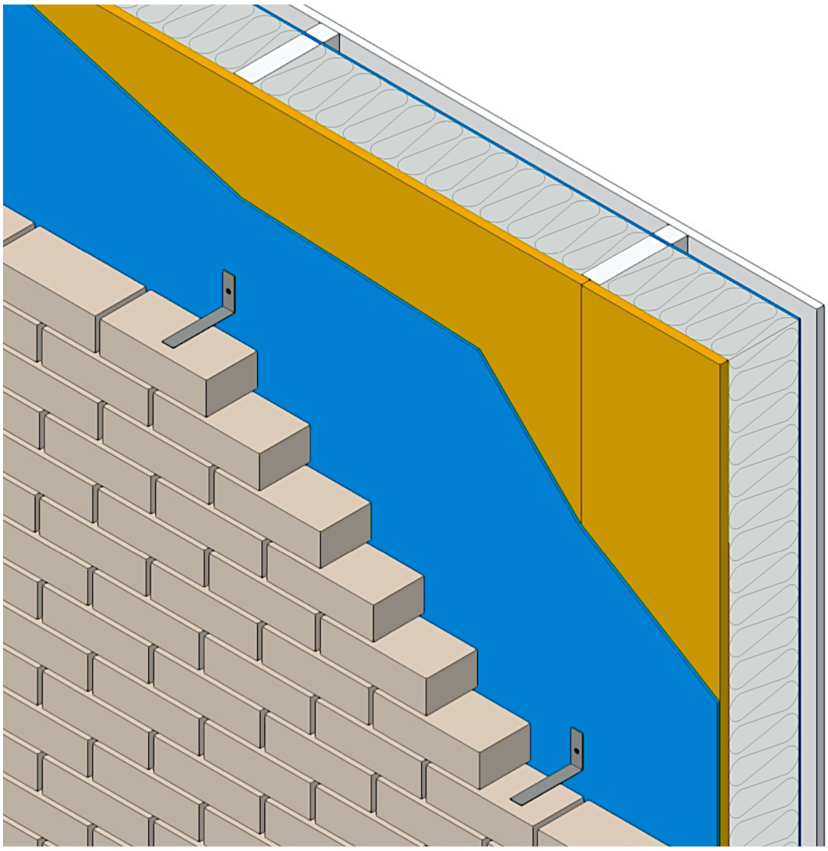


Figure 3.10: Brick outer leaf tied to timber framed wall panels at studs and headers

Detail 5: Floor OSB / Joist Connection

Floor cassettes are manufactured offsite and craned in on site. All ends and edges of OSB subflooring, other than tongued and grooved, are fully supported on joists or noggings. All short edge joints are staggered. OSB subflooring is glued to joists and nailed to joists at 150 mm centres.

Floor panels are erected by crane with operatives manoeuvring the panel into place, supported by the exterior and interior loadbearing walls. Junctions between the floor panels are secured to the neighbouring panel by oversailing the decking onto the last joist of previous floor cassette and nailing with 2.8x50mm treated nails @ 150mm c/c (Figure 3.11).

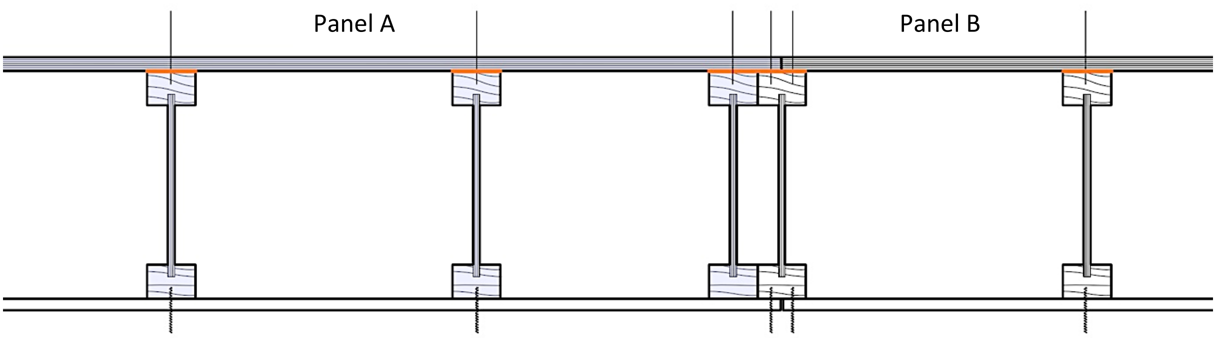


Figure 3.11: Floor panel to panel connection (red is glue line, OSB nailed to each joist)

Detail 6: Floor Joist Wall Connection

Floor Panels are secured to the head binders by nailing from the external side with 3.1x90mm treated nails @300mm c/c and at every joist (400mm c/c) from the internal side.

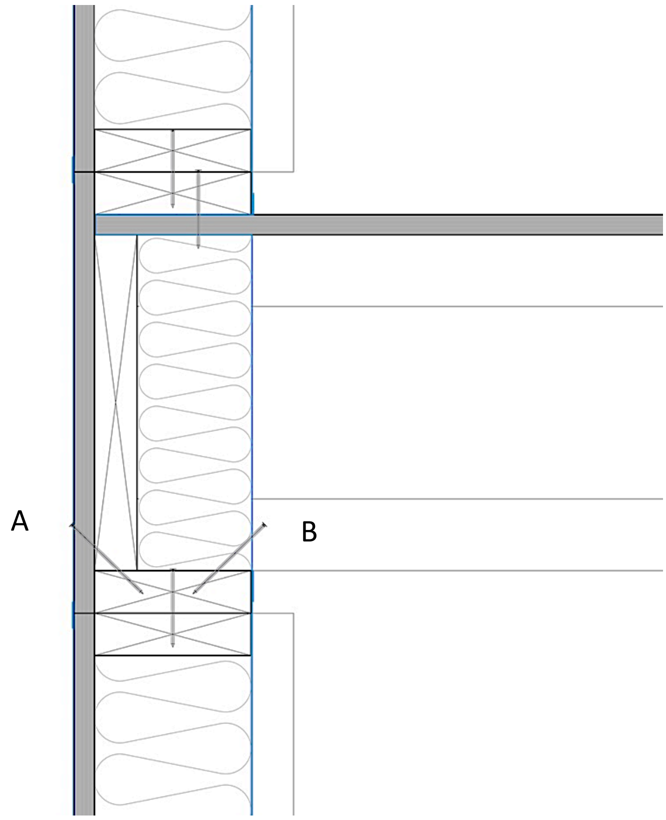


Figure 3.12: Floor panel to wall panel connection: toenail joist header to head binder (A) and toenail joist chord to head binder (B)

Cygnum Timber Frame undertook a review of replacing nails with screw connections in all wall connections, but from a site ease and speed of erection viewpoint it was decided to continue with nailed fixings. Some elements (such as restraining straps for brick work connections) use nails specifically, as a strong enough screw would necessitate a larger section of timber. The Cygnum analysis did not consider ease of deconstruction. However, they agreed that a timber frame dwelling could more easily disassembled using screws.

3.1.2 Presence of chemicals

The required standards for timber frame in Ireland state that structural elements should be preservative treated structural timber using a high pressure / vacuum process (I.S. EN 15228:2009). The preservative used is Protim E406. This process involves the immersion of the timber in a closed cylinder of preservative under pressure, and the excess removed with a vacuum (Woodspec, 2020).

Glue is used in the floors between the joists and OSB panels to reduce the risk of squeaking and increase stability during transport. Cygnum noted that glue use on floor decks is not essential.

3.1.3 Mechanical and electrical services connections to the load bearing structure

The current design utilises a concrete slab at ground floor level. Pop-ups for the wastes and incoming services are cast into this element. Electric cabling is left loose in stud walls to allow for movement should a wire be drilled inadvertently.

The current design allows for a service cavity at ceiling level at the first-floor ceiling as well as within exterior wall panels to avoid damage to the vapour barrier. Service cavities are absent from the ground floor ceiling level, where services can run between I-joists. Cygnum note that while pre-drilling could be undertaken at production, service routes through the joists in this case are cored out on site by the follow-on trades as they need them. Joist supplier guides are issued which provide information on allowable drilling to the main contractor (Figure 3.13).

Joist Depth (mm)	Joist Span (mm)	Hole Size (mm) 50		75		100		125		150		175		200	
		○+□	▭	○+□	▭	○+□	▭	○+□	▭	○+□	▭	○+□	▭	○+□	▭
220	3000	300	300	361	656	721	838	838	1159						
	3500	300	300	500	824	895	1024	1024	1375						
	4000	300	300	651	1001	1078	1216	1216	1596						
	4500	300	449	813	1186	1268	1415	1415	1819						
	4890	300	566	945	1334	1420	1574	1574	1996						
235	3000	300	300	300	566	656	873	873	1217						
	3500	300	300	325	725	824	1062	1062	1440						
	4000	300	300	463	894	1000	1258	1258	1665						
	4500	300	300	612	1072	1185	1460	1460	1893						
	5066	300	382	794	1282	1402	1693	1693	2154						
245	3000	300	300	300	482	586	865	865	1252	955	1252				
	3500	300	300	300	632	747	1053	1053	1478	1152	1478				
	4000	300	300	300	794	918	1248	1248	1706	1355	1706				
	4500	300	300	457	965	1097	1449	1449	1937	1563	1937				
	5184	300	300	666	1212	1353	1731	1731	2256	1854	2256				
300	4000	300	300	300	300	300	803	803	1308	1230	1542	1477	1883	1572	1883
	4500	300	300	300	300	300	975	975	1513	1430	1762	1693	2126	1795	2126
	5000	300	300	300	300	449	1154	1154	1722	1635	1985	1912	2369	2019	2369
	5500	300	300	300	535	670	1341	1341	1935	1844	2210	2135	2613	2247	2613
	5803	300	300	300	687	822	1456	1456	2066	1972	2348	2271	2761	2385	2761

Table 4. Allowable Locations for Circular, Square and Rectangular Holes (Domestic Applications)

Notes for Table 4:

1. Table 4 has been calculated for joists in intermediate domes tic floors (G_k=0.75kN/m^2,q_k=1.5kN/m^2,Q_k=2kN) at 600mm centres
2. Where more than one hole is to be cut, the minimum spacing between holes must be 2 times the width of the largest hole
3. The rectangular hole width b should not exceed 1.5xD
4. Cut all holes carefully, do not overcut and do not cut flanges
5. Where holes are required in rim and header joists of timber frame construction refer to the building designer
6. Plastic plumbing is ideal with JJI-Joists. Where copper plumbing is to be used, careful consideration of the sequence of pipe installation is required
7. The bearing support length used for this table is 45mm
8. A 35mm hole may be drilled any where on the centre line of the web material provided there is a minimum of 35mm from the edge of the hole to the end of the joist and it is not directly over a support

Service hole diagram

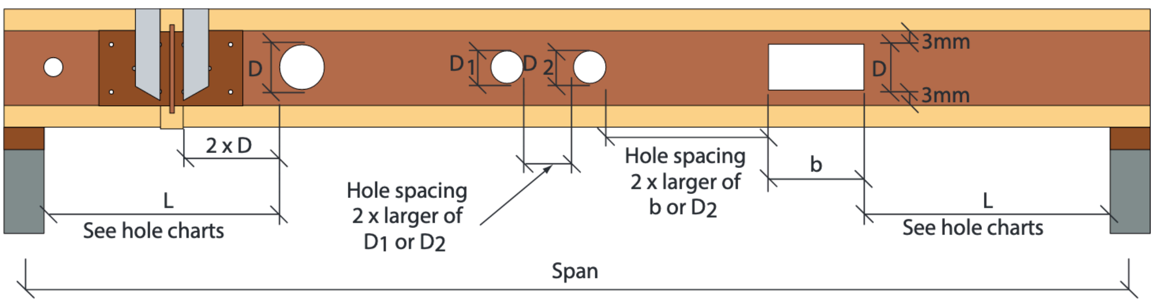


Figure 3.13: Allowable locations and dimensions of service holes in I-joists (James Jones & Sons)

Installations for water and sanitation are only partially rationalised in current plans to ensure a direct vertical run of services between the kitchen and bathroom on the first floor through the service cavity of a rear wall panel (see Figure 3.1), with the ground level washroom and utility room in an unrelated location that requires additional service runs through and under the concrete ground floor slab.

3.1.4 Assembly process for current design

Platform frame construction is the most common form of domestic timber construction. Every level is erected as a separate operation, with the ceiling of one floor providing the erection platform for the next. Panels are sized so they can be either handled by operatives or with the help of a crane. (Woodspec, 2020)

Most elements of the current design are prefabricated in the factory setting, including wall panels, floor panels and roof trusses, and transported to site for assembly. The remainder of the building is site assembled, including ground floor slabs and internal/external finishes.

- Foundations
    - Trenches are excavated for the foundations and ground levels reduced for the slab.
    - The foundations are poured, and rising walls of blockwork formed.
    - The hardcore and sand blinding is laid with an excavator and flatted. This is followed by the insulation, which is laid by hand, turned up at the edges to eliminate cold bridging.
    - A plastic separation layer is placed between the insulation and structural slab. The structural concrete slab is poured and acts as a subfloor.
- Ground Floor Walls
    - Sole plate is fixed to rising walls with Rawlplug screws. The centres of these fixings vary from 150 mm to 600 mm, depending on the engineering requirements. The fixings are positioned in the centre point of the upstand.
    - External wall panels, party wall panels and internal wall panels come to site fully enclosed. These are erected by crane with operatives manoeuvring the panel into place on the ground or on the first-floor platform after the first-floor joists have been installed. The bottom rail of the panels is fixed with nails to the sole plate at a minimum of one per stud bay. An additional fixing is required either side of a window opening greater than 2 m wide.
    - The panels, once erected, are fixed together at junctions using nails at maximum 300 mm centres vertically.
    - A head binder is fixed with nails to the top of the panels to tie together the wall assemblies.
    - Externally, the breather membrane is stapled to the timber frame panels at 150 mm centres with stainless steel staples.

- First Floor Structure
    - The I-joists are pre-cut with OSB subflooring glued and nailed to the joists and delivered to site as composite floor panels.
    - Floor panels are erected by crane with operatives manoeuvring the panel into place, supported by the exterior and interior loadbearing walls. Panels are secured to head binder by nailing from the external side with 3.1mm x 90mm treated nails at 300mm on centre and at every joist at 400mm on centre from the internal side.
    - Junctions between the floor panels are secured to the neighbouring panel by oversailing the decking onto the last joist of previous floor cassette and nailing with 2.8mm x 50mm treated nails at 150mm on centre.
    - The foil backed vapor control layer (VCL) from wall panels below taped to FCM 750 airtight membrane for floor wall junctions.
    - Sole plate is nailed at the wall locations at 600mm on centre.
- First Floor Walls
    - Same sequence as ground floor walls
- Roof
    - Engineered trusses are fabricated off site and installed independently.
    - The engineered trusses are connected to the wall plates with a truss clip which is nailed to the wall panel head binder and truss top rail.
    - Longitudinal (binder) and diagonal bracing provide rigidity.
    - Insulation is placed at ceiling level and the roof space is fully ventilated via the eaves.
    - A roofing breather membrane is stapled on top of the truss, followed by battens.
    - Insulation is site fitted (friction fit) between and over the ceiling from above.
    - Slates are fixed with clout nails to the battens below.
    - Service cavity is formed by fixing battens with nails to the ceiling joists.
- Services and Internal Finishes
    - Electrical and plumbing service lines are installed within service cavities formed by battens in the exterior wall panels.
    - Finished flooring is installed.
    - The inner layer of plasterboard is added onsite, using drywall screws, skimmed, and painted. Plasterboard is screwed to the ceiling, either directly to I-joists on the ground floor ceiling or via service batten on the first-floor ceiling, and to the battens on the exterior wall panels and directly on the internal walls. Skirting boards, conceal the joint between the plasterboard and finished floor, are fixed with dabs of adhesive followed by mechanical fixings.

- External Finishes
    - External leaf wall ties are nailed to the panels on site to align with the studwork behind the sheathing. They are at 450 mm vertical centres to align with mortar joints.
    - External masonry leaf is erected. This masonry outer leaf is a 100 mm concrete blockwork in a runner bond and sand cement mortar.
    - The truss ends overhang the final external wall surface to create an eaves. The eaves soffit is formed with a right-angled boxing made of treated softwood timber nailed to the rafter ends.
    - PVC fascia and soffit are fixed with PVC headed nails.

3.2 Deconstruction process

The current deconstruction would potentially result in the prefabricated wall, floor and roof components being recovered in the reverse sequence to the assembly for a second use. While in other case studies involving 2D panel systems (Sweden, UK) the intention would be for these large panels to be reused directly in their current form on another construction project, in this case study we are examining the recapture rate if the panels are disassembled. This provides an estimate of the ultimate recovery rate for similar systems, following their second reuse as panels, and provides a reference point to a study of onsite light timber platform framing construction.

Stage 1

Non-structural elements removed.

- Internal applied elements: Kitchens, skirtings, doors, architraves would be removed first, many of which would be wood, or wood based. It is not possible to say exactly how these elements are fixed as it can vary significantly. Given the high turnover of these elements during the lifecycle of the building they may lack consistency in how they are fixed. Any process would begin with an investigation of the fixing method. Then an appropriate removal method would be undertaken. Kitchen units, doors and frames will be screwed in place. Architraves and skirtings will be glued or nailed which would be levered off. Note: A window may be removed at this stage to enable the removal of internal fixtures. (See note on windows in Stage 3).
- Electrical Services: Second fix items such as light fittings, sockets, switches, are screwed to metal junction boxes. These can be unscrewed.
- Floor Linings: The floor linings are installed or changed by the tenant. Common finishes include carpet, timber flooring, tiling. Laminate timber floors can be floating and are easily removed by hand. Carpet however may have a glued cushion layer beneath which can make removal difficult. Tiles will be fixed with an adhesive and grout. Removal of the surface finish may be straightforward however the fixing substrata of adhesive will be very difficult to remove.

- Mechanical Services: second fix elements may be left till next stage for convenience as the services running to them may still be live and require a plumber and to facilitate disassembly. This may be to water down dusty environments or clean equipment or removed items.

Stage 2

- Internal Wall lining: Plasterboard is screwed into place then skim coated with plaster. It would not be possible to easily locate all screws and therefore the internal plaster board lining is removed by being cut away using a claw hammer and saw.
- Roof insulation: The insulation friction fitted over and between the truss are removed.
- Mechanical services: First and second fix elements such as radiators, taps, hot and cold water and heating are removed.
- Electrical Services: Any second fix elements such as wiring and data cables. A certain proportion of first and second fix elements may be retained till late in the process to facilitate disassembly. This may be to charge or power tools.

Stage 3

- Roof tiles: These are attached with clout nails to battens. They are removed along with ancillary rainwater goods, fascia and soffit using a claw hammer. External roof battens, nailed through the breather membrane to the roof trusses are removed at this stage also using a claw hammer or pry bar.
- External Wall finishes: Typically, a rendered blockwork or brickwork outer leaf. When bonded with a sand cement render it will be difficult to remove and will be take down with a pneumatic hammer.
- Doors and windows: Depending on the installation, the doors and windows are removed before or after the external lining is removed. The galvanised straps which connect these elements to the timber frame inner leaf are screwed.
- Sills: These can be aluminium or masonry and are removed with the external lining. Aluminium sills will be screwed in place can be unscrewed while a concrete sill will be removed along with the masonry outer leaf.
- Membranes: All external membranes, attached with stainless steel staples, are removed by being ripped from the face of the panels or roof. The staples that remain can either be hammered into the surface or removed with some pliers. Vapour control layers which are part of the original prefabricated units remain in place. The membranes will not be reusable.

Stage 4

- Roof structure: Following removal of the tiles and roof membrane, the roof is ready to be removed. Internal bracing which has been nailed within the attic space is removed using a claw hammer. If the nails in the truss clips are not possible to be removed, the clips would be cut out. The trusses may be lifted as one or individually.
- First floor walls: The framed panels are sequentially removed from the first-floor platform. Removing nails at 300 mm centres vertically where possible, temporary works may be required to take these elements apart, such as bracing ties. If nails cannot be removed, then a vertical saw cut will be required. A straight cut may be difficult to achieve which will lead to

post deconstruction treatment. The wall panels may lever the nails in bottom plate out due to their weight. These panels would then be dropped to ground level for final disassembly.

- First Floor Panels: As the OSB tongue and groove sheets are glued, the construction must be cut apart using a sabre saw. The floor panels are removed by crane in whole elements therefore the screw fixings between the sheets and the joists will remain in place. The panel will be cut away from the ring joist. Neither OSB or I-joists will be reused.
- The ground floor walls are removed in a similar manner to the first floor.
- Sole plates which are screwed to the rising wall are removed from the concrete structure by unscrewing.

Stage 5

- Concrete substructure: Removed with an excavator.

3.3 Advantages and Disadvantages

Advantages for DfDR in the current design.

- Potential to reuse structural wall panels if they can be removed without damage. Roof trusses can also be reused if undamaged. Cygnum advises against using I-joists floor panels for a second use.
- The current assembly takes place off site, however much of the work is still undertaken by hand. This results in large planar elements which might be fully disassembled or reused.
- The current design utilises materials efficiently, with full sized elements such as OSB sheathing and flooring, joists, and studs, all used to maximise economy.
- Engineered trusses may be reused if the truss clip is located at a low enough level.

Potential Obstacles to DfDR in the current design.

- Service runs are not organised to enable replacement/maintenance. Otherwise, joists may be either notched or cored to allow for passage of services.
- Large panelised system means reuse of composite panel would be highly specific.
- Current general layout plan leads to high variability of unit lengths of structural members.
- Highly engineered layout results in limited scope of potential uses. For example, roof structure difficult to adapt for conversion of roof and difficult to expand.
- Some elements such as studs are too narrow to allow for screw fixing in certain locations.
- First floor formed of I-joists are unlikely to be reusable due to low material quality and potential degradation of joists.
- T&G flooring difficult to remove individually due to glued joints.
- Floor cassettes nailed very frequently making disassembly without damage difficult.

- Locating nail joints between wall panels maybe difficult, and removal may be difficult. This could result in saw cutting the joints which could damage the studs.

In addition to the obstacles to DfDR, the configuration of spaces in the current design makes adaptive use during the service-life of the building difficult.

3.4 Potential for improvement

A summary of potential Improvements to the current design are as follows.

- Reconfiguration of plan to: allow for greater adaptability to extend service life and; utilize full factory-sized timber to alleviate construction waste.
- Services centralised: as part of the reconfiguration of the layout
- Select more robust materials with greater longevity to increase opportunity for reuse, such as solid joists rather than OSB I-Joists.
- Utilize wood nails and/or screw connections in timber frame to allow for ease of cutting or removal.
- Roof structure connection: Truss clip location could be reconsidered to allow for sacrificial area enabling reuse of the engineered trusses.
- Locally removable internal lining to allow for adaptability of services to extend lifespan and reduce waste.
- Omit glue between deck and floor joists.
- Prepare Material Inventory & Disassembly Plan

3.5 Selection of areas to improve within this study

The selected areas of the design to be improved are as follows.

- Reconfiguration of plan to: allow for greater adaptability to extend service life; and utilize full factory-sized timber to alleviate construction waste.
- Services centralised: as part of the reconfiguration of the layout
- Select more robust materials with greater longevity to increase opportunity for reuse, such as solid joists rather than OSB I-Joists.
- Utilize wood nails and/or screw connections to allow for ease of cutting or removal.
- Omit glue between deck and floor joists.
- Prepare Material Inventory & Disassembly Plan

3.6 Amount of wood that can be reused from the current design

The following assumptions have been made in calculating the amount of timber available for reuse from the current design (for one house only):

- Lengths of less than 1 metre have been omitted: though it may be possible to reuse these elements, they will likely have a high proportion of penetrations per linear meter and therefore their reuse is less likely.

- OSB or elements which contain OSB have been omitted. OSB is formed with high amounts of glue and recycled product. Further investigation is required into the warranty of the glue's properties beyond the initial product life.

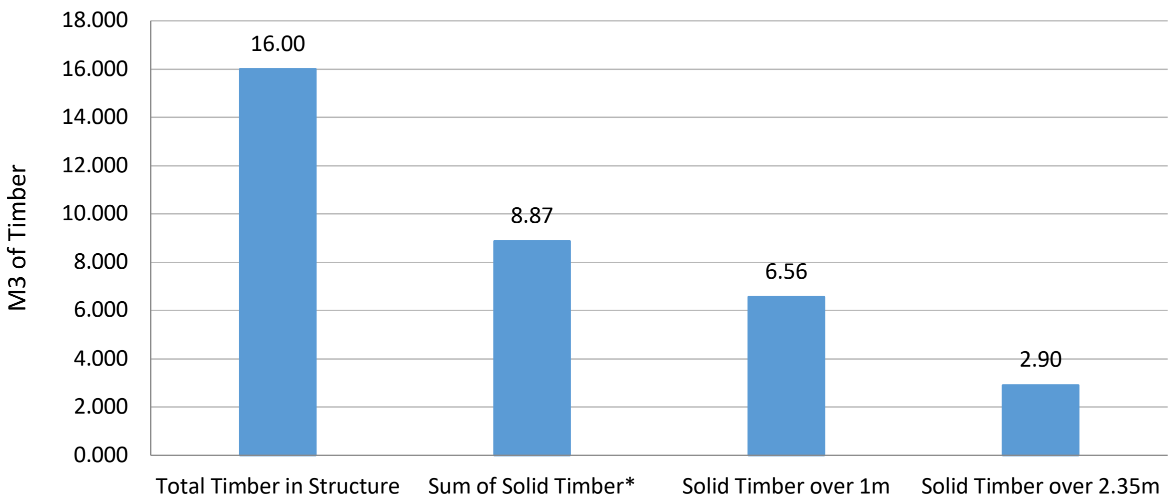
- External and internal battens have been omitted. Due to the small section sizes and the penetrations every 400 mm approximately, the value of these elements would be limited. The sole plate is not considered for reuse as it will have a high number of fixings per linear meter and potentially weathered.

- Reduced Length of Solid Timber: To reduce the risk of nails remaining in elements removed or of honeycombing at element ends, it is assumed that 100 mm would be removed from both ends of each timber element.

- The minimum reusable length of timber has been defined as 2350 mm as this length is allows for use as stud in a wall panel achieving at least 2400 mm floor to ceiling height. (38 mm + 2350 mm + 38 mm).

The current design has approximately 16 m³ of timber (solid timber, I-joists, and wood-based structural panels) in the structure of one house of the semi-detached pair of houses. It is estimated that 6.6 m³ or 41.2% of this timber could be reused (Chart 3.1). However, as there is an assumption that the ends of each element may be removed to eliminate nails (up to 100 mm at each end), this may limit the options for reuse. For example, a stud of 2450 may be reduced to 2250 making It less likely to be reused as a stud.

Chart 3.1 Quantity of Structural Timber in Cygnum Design - One House only



3.7 Modified design

3.7.1 New design concept: Adaptability through to Reuse

With the aim of adding to the lifespan of the proposed structure, the internal configuration of the space has been considered to increase the flexibility and adaptability of the space as well as the efficiency.

DfA: Efficiency, Adaptability and Flexibility

Floor Layout Changes (Figure 3.14):

- **Entrance Location:** The primary entrance to the house is relocated to the side. Though an option for a front entrance may be maintained, the new location eliminates the need for a long entrance corridor. This provides an opportunity for a future study or single bedroom at ground floor level (dotted in plan).

- **Centralisation of Services:** The new layout positions the bathrooms above each other at ground and first floor (highlighted in blue). The services are therefore centralised which would allow for a greater amount of flexibility later and simplify disassembly / deconstruction. The linings to these areas are designed to be removable allowing even more accessibility to services.

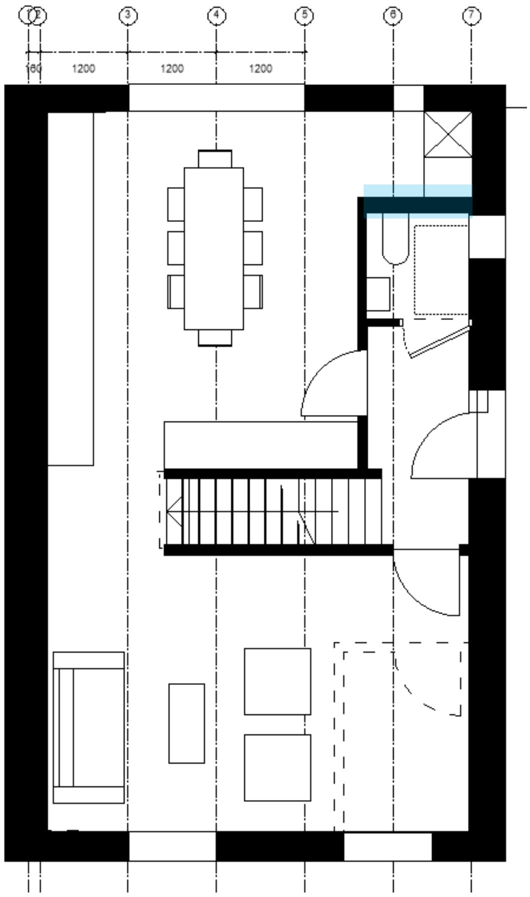
- **First Floor Layout:** The first-floor layout is reconfigured to provide three double bedrooms. The opportunity to install a stair to the attic is maintained at landing level (see below note on cut truss roof).

- **Roof Structure:** Cut truss roof will allow for greater adaptability into the future (Figure 3.15). This will provide more opportunity for storage and scope for the addition of another room. The pitch of the roof could also be adjusted to allow greater scope for change.

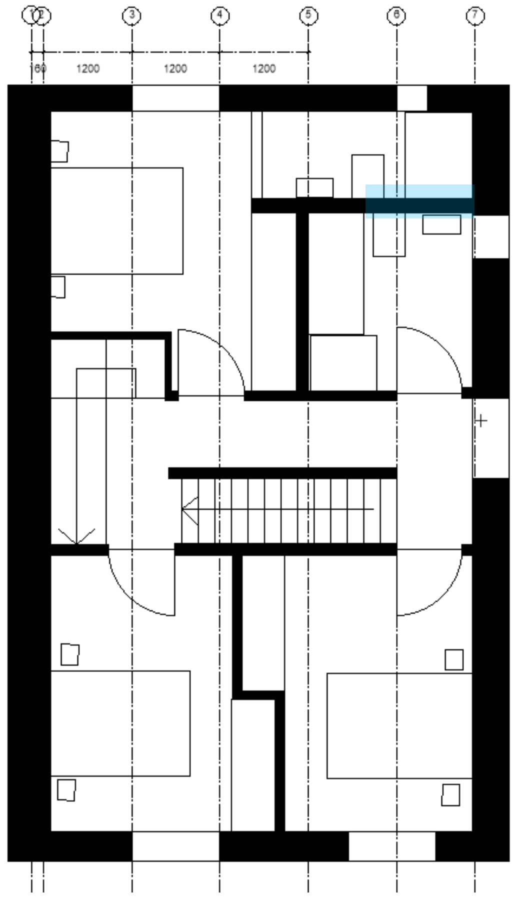
- **Joist Span Direction:** The joist layout at first floor level has been reconfigured to utilise standard full-length solid joists where possible. The joists span from party wall to side wall which would allow the accommodation to be extended without the need for a down stand beam at the rear.

- **Removable linings:** Certain internal walls are designed to allow for access to electrical and mechanical services using hinged internal wall panels (Figure 3.16).

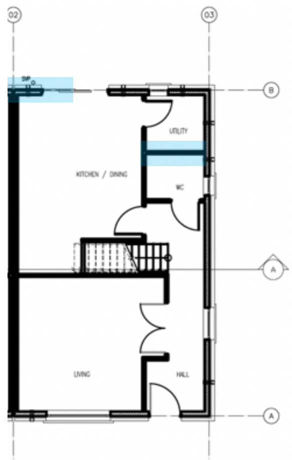
To facilitate a meaningful comparison of recovery rates to the original design, the ground floor structure is assumed to be a concrete slab with masonry upstands as per the original design. However, in an optimum scenario the ground floor would be framed as a suspended timber floor. This suspended structure would allow for access from above to mechanical, electrical, and plumbing services that would be run underneath through insulated pipework and loose cabling.



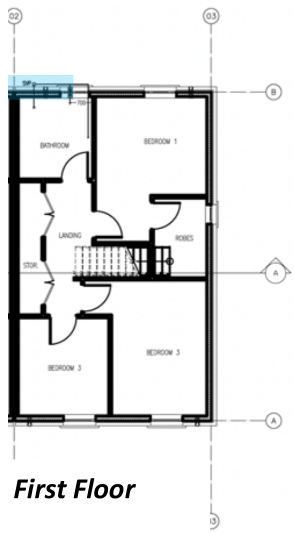
Ground Floor



First Floor



Ground Floor



First Floor

Figure 3.14: Revised Floor Layout (left) and previous layout (right) (Walsh 2021)

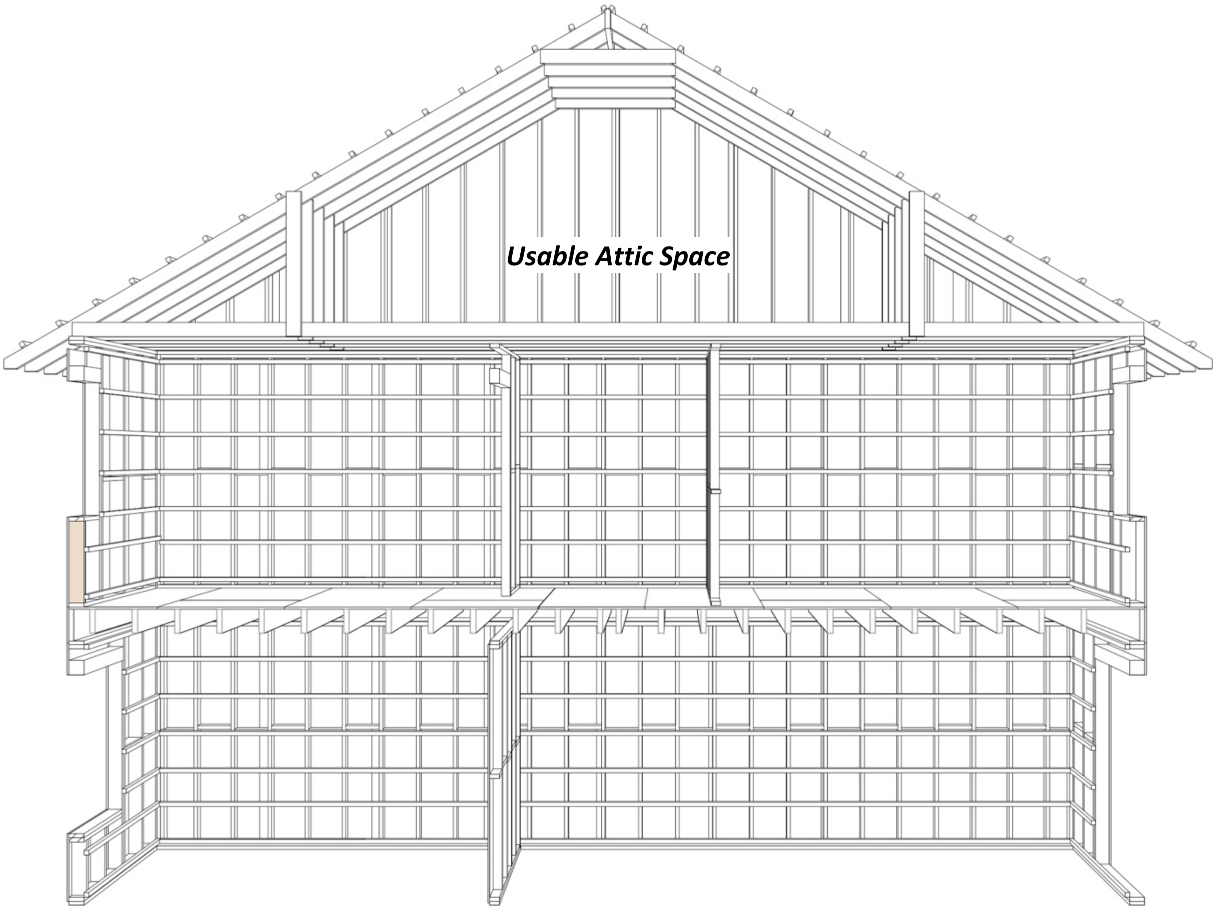


Figure 3.15: Revised Section layout with framed roof allowing future occupation (Walsh 2021)

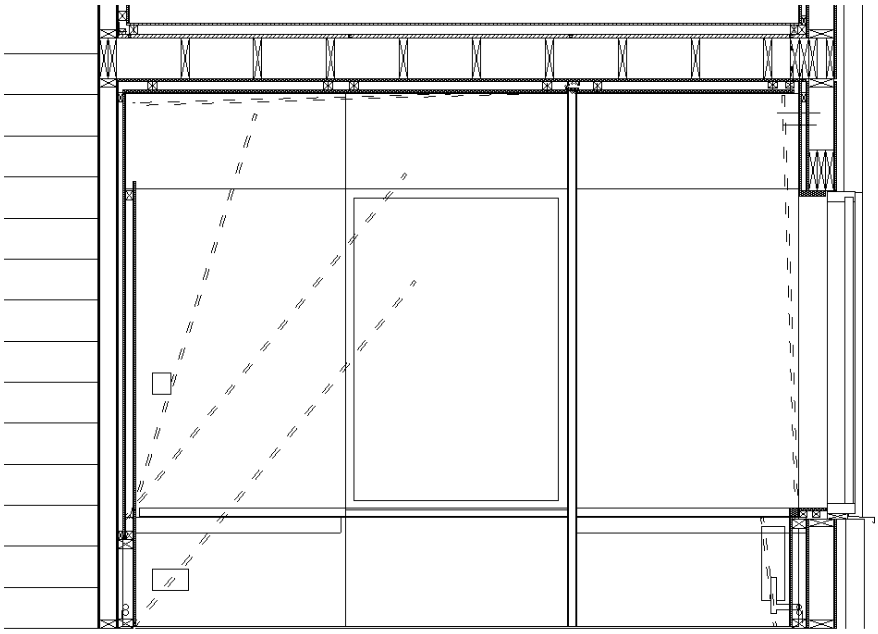


Figure 3.16: Revised Section with hinged wall panels to facilitate service maintenance and changes (Walsh 2021)

3.7.2 Changing specification for increased reusability

It is not envisaged the I-joists would be reusable in the future, given the material quality. There is also limited research on the longevity of the glues used. Therefore, the proposal includes the use of solid joists instead which will be more reusable in the future. The capital cost of this may prove a challenge to implementing the change.

The change from I-Joists to solid joists increased the overall volume of timber in the house. A 4.8m length of 225 x 75mm joist has a volume of 0.081 m^3. By comparison, a 38 x 300mm I-Joist of similar length and dimensions has a volume of 0.034 m^3. This equates to almost 2.4 times the quantity of timber. Some positive and potentially negative implications of this decision are as follows:

Benefits

- Avoid use of adhesives and chemicals in building products
- Higher rate of recovery and reuse
- More reusable timber in the building
- Higher quality product with less likelihood of failure

Challenges

- Larger sections of virgin timber required, unless adequate sources of second-use timber are found
- Greater capital cost may impact on the choice of timber frame as a construction method
- Larger self-weight on walls and foundations

3.7.3 Adjustment of fixing method to increase reuse potential

Eurocode sizing

Currently a timber stud is fixed to a bottom rail using nail connections. For a 140 mm external wall stud, three nail fixings are required while for an 89 mm internal stud, two fixings. The nails used are 3.1 mm wide, with a penetration depth in the stud of 8*d* (IS EN 1995-1-1:2004/clause 8.3.2.7). Cygnum uses a nail size of 3.1 x 90mm both for primary framing as well as panel to panel connections.

Screw Fixings to 140 mm Dimensioned Stud

The feasibility of using screws instead of nails using guidance from IS EN 1995-1-1:2004 was analysed (Figure 3.17). A comparable size to the current nails used by Cygnum would be a 4.2 x 80mm self-tapping screw. The use of a 4.2 mm screw would technically allow for 6 penetrations to be made across the depth of a 140mm stud (Table 3.3), suggesting that a stud may be reused twice if the holes are used only once. Screws of any larger diameter (5.5, 6.3mm) may be problematic, as the spacing required for two sets of fixings is larger than the given width. Equally, fixing a screw of larger dimension to the short dimension of the stud (38mm) is also problematic. The section size would have to increase by 6 mm to use a 5.5 mm screw and by 12.4 mm to use a 6.3 mm screw, which argues against the use of larger screws for either the first or second use.

The 140mm stud depth is standard for external loadbearing wales in Ireland. The standard 89mm stud depth, a typical size used in Irish timber framing for interior walls fastened with 2 rather than 3 nails or screws, would not accommodate a second set of screw attachments using a 4.2mm screw.

8.7.2 Axially loaded screws

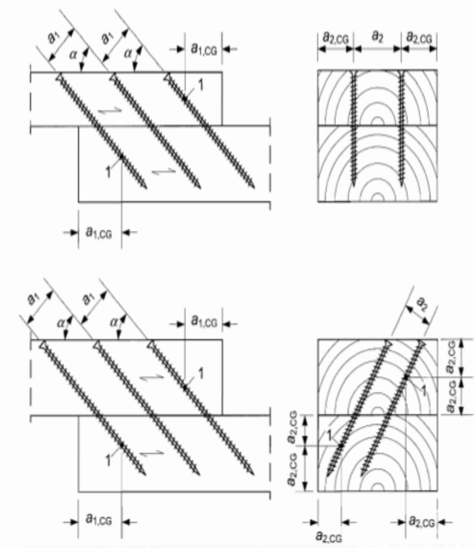
(1)P For the verification of resistance of axially loaded screws, the following failure modes shall be taken into account:

- the withdrawal failure of the threaded part of the screw;
- the tear-off failure of the screw head of screws used in combination with steel plates, the tear-off resistance of the screw head should be greater than the tensile strength of the screw;
- the pull-through failure of the screw head;
- the tensile failure of the screw;
- the buckling failure of the screw when loaded in compression;
- failure along the circumference of a group of screws used in conjunction with steel plates (block shear or plug shear);

(2) Minimum spacings and end and edge distances for axially loaded screws, see figure 8.11a, should be taken from Table 8.6, provided the timber thickness $t \geq 12d$.

Table 8.6 – Minimum spacings and end and edge distances for axially loaded screws

Minimum screw spacing in a plane parallel to the grain a_1	Minimum screw spacing perpendicular to a plane parallel to the grain a_2	Minimum end distance of the centre of gravity of the threaded part of the screw in the member $a_{1,CG}$	Minimum edge distance of the centre of gravity of the threaded part of the screw in the member $a_{2,CG}$
$7d$	$5d$	$10d$	$4d$



Key: 1 Centre of gravity of the threaded part of the screw in the member

Figure 8.11.a – Spacings and end and edge distances

Figure 3.17: Section 8 guidance on axially loaded screws (IS EN 1995-1-1:2004)

Table 3.3 Spacing of Screws in 38 x 140 mm stud on first and second use

Screw Size		First Use			Second Use				Total Spacing required
Diameter mm	4.2	Spacing to Edge	Spacing between Screws		Spacing between screws			Spacing to Edge	
Length mm	80	a2	a2cg	a2cg	a2cg	a2cg	a2cg	a2	mm
Stud Depth	**140mm**	(4d)	Screw 1 to 2 (5d)	Screw 2 to 3 (5d)	Screw 3 to 4 (5d)	Screw 4 to 5 (5d)	Screw 5 to 6 (5d)	(4d)	
	3 screws	16.8	21	21				16.8	75.6
	6 screws	16.8	21	21	21	21	21	16.8	138.6
Stud Width	**38mm**	(4d)						(4d)	
	1 screws	16.8						16.8	33.6

This analysis of the implications of Eurocode on the ability to reuse timber elements in this application highlighted some issues. Though numerically there is room for six equally spaced screws in a 38 x 140mm stud, the layout of this suggests that the first set would have to be carefully set out to enable a second series of screws if they were attached from the rail into the end grain as is typically done (Figure 3.18a & b). If an operative is to reuse an existing stud using the technique described above, the previous holes will be obscured by the respective rail to which it is to be fixed. It will therefore not be possible, or at least very difficult, to know exactly where the hole from the previous penetration is on the underside of the stud and consequently, the distance required for any new fixings. This careful locating of screws would be difficult to achieve on site, unless the studs were toenailed to the rails which would make the attachment points visible. Likewise, if one were to propose locating larger screws in previous 4.2mm screw locations, the difficulty is in locating them precisely, unless the toenail method is used.

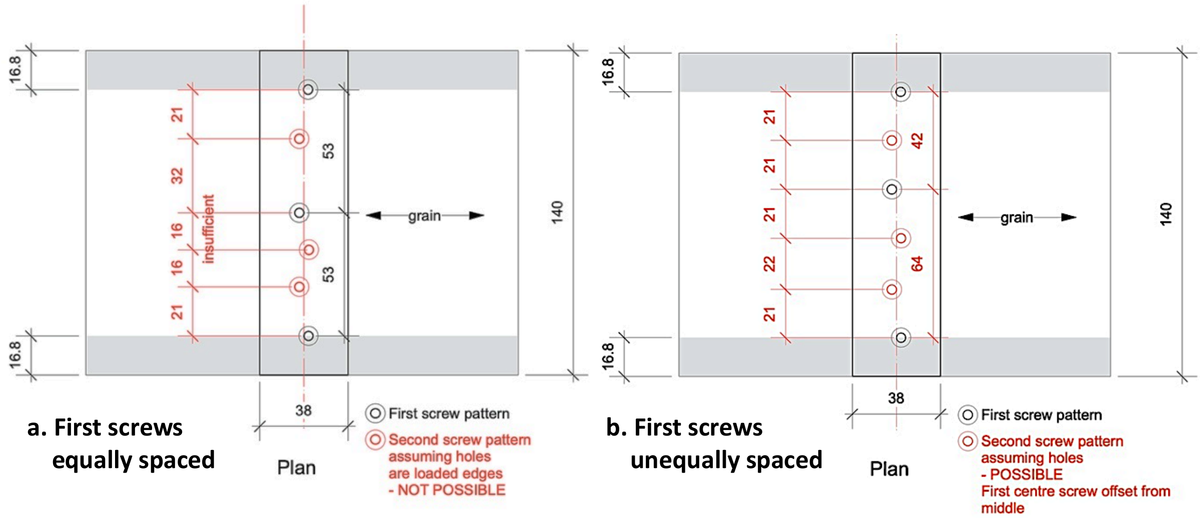


Figure 3.18a & b: First and second (red) use screw locations in 140mm stud (Shotton 2021)

Several strategies to overcome these problems with connections in reuse scenarios were discussed by the team and are summarized in Table 3.4. The logic and ease of using wood nails in the project appeared to have the most promise and was further analyzed.

Table 3.4 Summary of Alternative Fixing Mechanisms and Reuse Strategies

Option 1 Fill the hole in the bottom or top of the stud with wood filler of with a greater strength than the timber itself.	**Pro** No change to fixing methodology required
	Con Time taken to fill hole makes it time and cost ineffective
Option 2 Toenail the stud on second and / or first use.	**Pro** No need for remedial work to the stud Visible later when internal linings removed
	Con Not as standard a methodology as previous Two fixings required at each end
Option 3 Other alternative fixings may be brackets.	**Pro** Reusable fixings Visible to a deconstruction contractor Can be bolted connections or screwed Not limited to a small area around base of stud

	Con Expensive, resource inefficient Over engineered compared to the current nailed solution Not appropriate for small scale construction
Option 4 Wooden nails allow for elements to be quickly cut apart using a sabre saw.	**Pro** Quick installation Allows for disassembly using saw without risk of damage to blade
	Con Difficult to remove planar elements (eg. OSB) from linear elements (studs), or head binders to top rails of walls Requires additional tool

Wood Nails

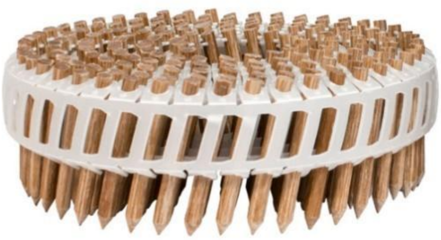


Figure 3.19: Wood nail cartridge for wood nail gun (Lignoloc)

The utilisation of wood nails (Figure 3.19) to replace metal nails or screws requires greater investigation both in structural terms (embedment strength) and ease of disassembly through lab-scale prototype studies, which was not possible during the Covid-19 pandemic. However, wood nails have the potential to improve the recoverability and reuse of timber studs, joists, and rails by eliminating the difficulty of locating the second fixings relative to previous holes made in the timber.

The benefits of using wood nails to replace metal nails or screws in primary framing would include:

- No residual metallic nails or screws in the timber
- Honeycombing of timber ends due to fixings no longer an issue
- Simpler demolition as no need to locate screws

Potential challenges to the use of wooden nails include:

- Expense of purchasing additional technology to screw and/or nail guns
- Not appropriate for all connections, with a self-tapping screw easier to remove in some conditions
- If no disassembly information record is available, the fixing may not be evident to those deconstructing the building.

For linear elements such as studs and joists, the removal would be straightforward as a sabre saw can be used at the joint to sever studs from the rails. Typically, a timber frame wall panel is constructed by nailing through the top or bottom rail to the studs. This unit is then sheathed to provide rigidity. The major benefits are the absence of screws and/or nails residing in the wood after recovery and the lack of holes that remain following removal of screws and/or nails. This last issue is a distinct advantage, as the studs and rails would effectively be solid wood composites, with the wood nails remaining in place, thus allowing for multiple reuses and reattachments.

Connections between Panels

The option of using timber nails to join panels were discussed. Though there is a simplicity to this option, the issue with sawing panels apart may be the straightness of the cut achieved if using a sabre saw. Given the screws can be easily used for this task, it seems unnecessary to do this.

Ceiling Battens

The option of using a packer to space the fixing of two elements may be possible for removal of these with a saw (if using wooden nails), however this is a time-consuming process. Screws are more appropriate for disassembly.

Roof Truss

This may be quite a suitable location for the use of wood nails which could be face applied to a connection between two elements

Sub Flooring & Wall Sheathing

As noted above, planar elements will be difficult to remove when fixed with wood nails as the nail welds to the internal faces of the penetration. In this case, a screwed or metal nail connection would be best.

Therefore, wood nails may be best used in assembly the main timber frame elements (stud to rail), joists (joists to headers), and rafter member connections.

3.7.4 Amount of wood that can be reused with modified design

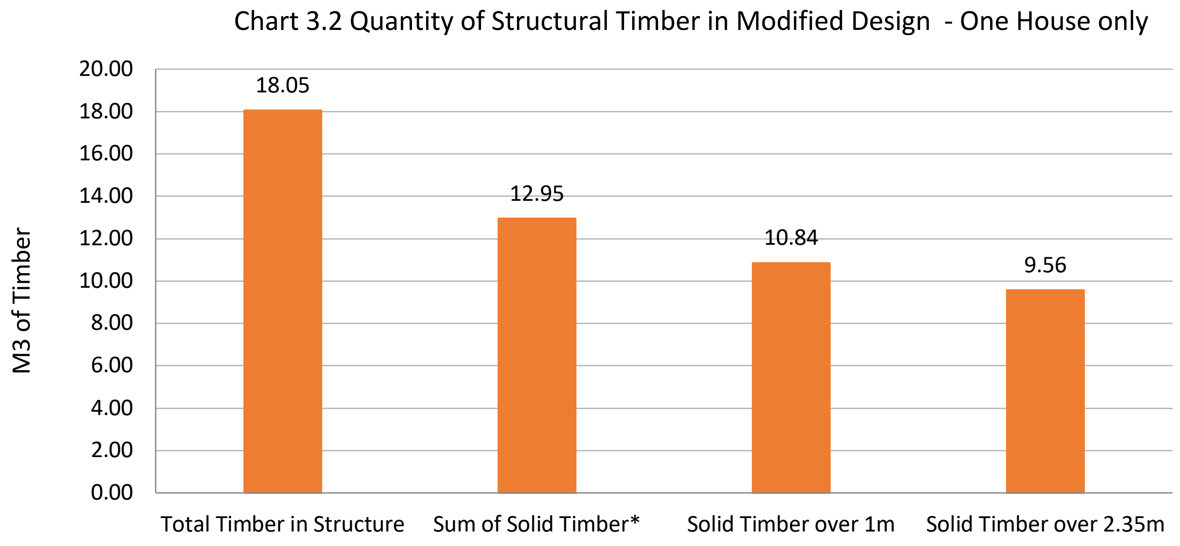
The following assumptions have been made in calculating the amount of timber available for reuse from the modified design (for one house only):

- Lengths of less than 1 metre have been omitted: though it may be possible to reuse these elements, they will likely have a high proportion of penetrations per linear meter and therefore their reuse is less likely.
- OSB or elements which contain OSB have been omitted: OSB is formed with high amounts of glue and recycled product. Further investigation is required into the warranty of the glue's properties beyond the initial product life.
- External and internal Battens have been omitted: Due to the small section sizes and the penetrations every 400 mm approximately, the value of these elements would be limited. The sole plate is not considered for reuse as it will have a high number of fixings per linear meter and potentially weathered.

- 2350 mm is taken as a minimum length as this allows for use as stud in a wall panel achieving at least 2400 mm floor to ceiling height. (38 mm + 2350 mm + 38 mm).

- Wood nails have been used in the primary construction of walls, floors, and roof trusses

The proposed design has approximately 18.05 m³ of timber in the structure (Chart 3.2). It is estimated that 10.84 m³ (60%) of this timber that is over 1m in length could be reused. Through the use of wood nails, many of these elements can be extracted in their factory dimension, without need for trimming, resulting in a recovery rate of 74% for solid timber material in lengths of over 2.35m.



3.7.5 Comparison current design – modified design

The modified design has a small increase (2.05m³) in all timber material when compared to the existing Cygnum structure (Chart 3.3). This is a result of the adjustments to the layout of the interior spaces and solid joists at first floor level. For comparison purposes the ground floor in the modified design was still modelled as a concrete slab on grade.

The re-design has led to the following differences:

- Moderate increase (12.8%) in the volume of timber products in the structure
- Increase of 46% in the amount of solid timber used
- Significant increase in the material volumes of timber material recovered (60% vs 41%)
- A shallower rate of material loss is seen across material lengths
- A greater quantity of longer lengths of timber (>2350mm) can be reused from the proposed design (74% of solid timber in design)

This analysis highlights that a different factor needs to be considered when evaluating the material extracted from a structure. Though the overall volume of timber recoverable from the modified design exceeds the existing design (71.7% vs 55%), what becomes apparent in breaking this down further by recoverable length is that the quality of the extracted material is significantly higher in the modified design. This is due to the greater quantity of elements of a length more than 2350 mm, which increases its reusability in the marketplace. When coupled with the use of wood nails in the main frame, which ensures that the substrate can received additional nails in a second use, this gives the modified design not only considerably higher recovery rate but recovers over 3 times as much material with the greatest reuse value of 2350 mm length or greater (Chart 3.4).

Chart 3.3 Quantity of Structural Timber in Cygnum vs Modified Design
One House only

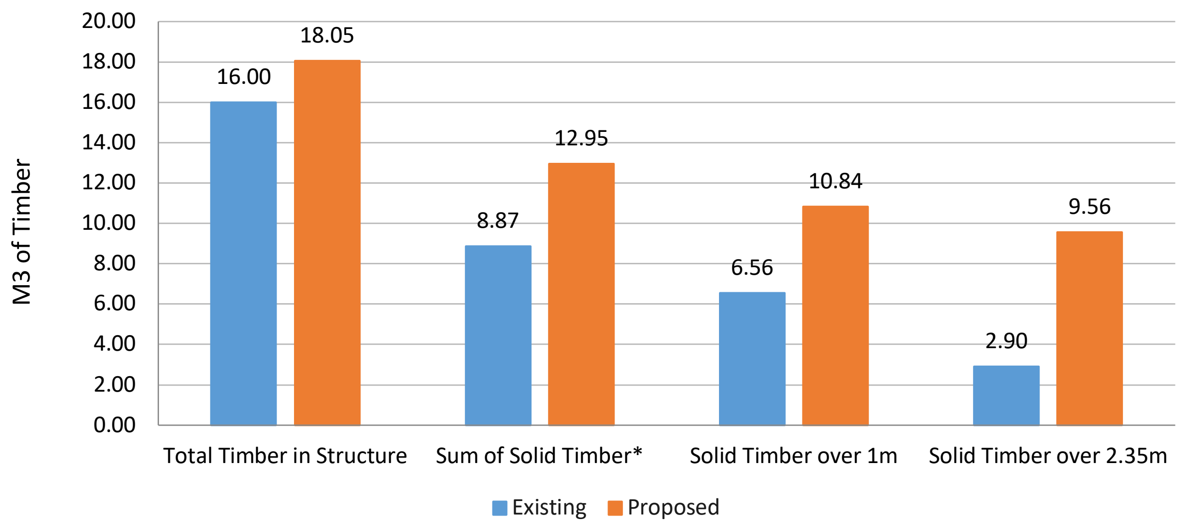
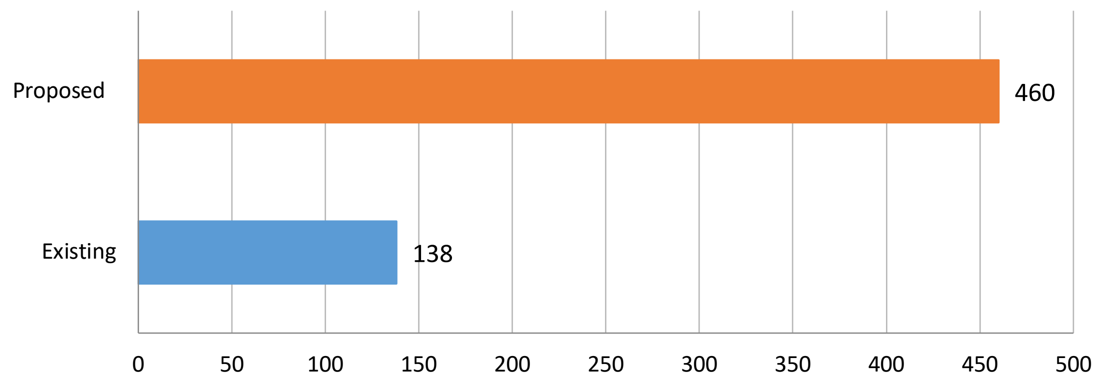
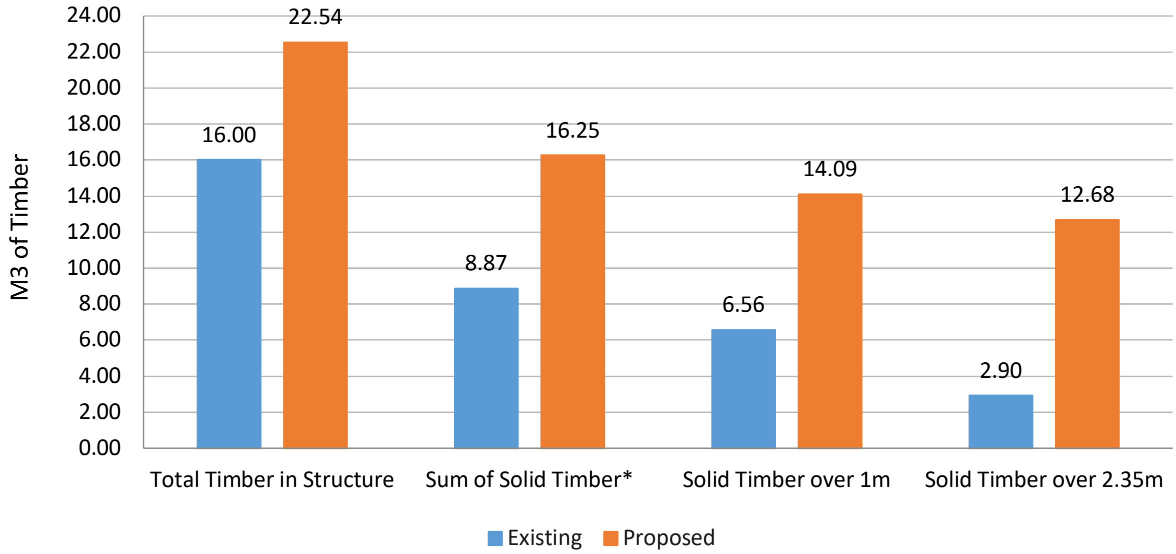


Chart 3.4 Quantity of Timber Elements over 2.35m
in Existing vs Modified Designs



This analysis was based on retaining the concrete ground floor slab in the modified design, to ensure comparability of timber quantities and recovery rates to the original Cygnum design. Ideally a modified design would be constructed with a timber-framed floor structure at ground level, to eliminate the use of cast-in-situ concrete and facilitate access to services under the ground floor. When this alternative scenario is modelled in BIM the quantity of wood-based products in the design increases by nearly 40.9% from the existing Cygnum design and 24.9% from the modified design, with the percentage of recoverable solid timber over 2.35m increasing slightly to 78% of all solid timber from the previous 74% for the modified design with concrete slab (Chart 3.5).

Chart 3.5 Quantity of Structural Timber in Cygnum vs Modified Design with timber-framed ground floor
One House only



3.8 Guidelines for deconstruction & reuse: Disassembly Information Record (DIR)

An attempt has been made to generate this document from first principles taking into account the work practices of Architects, who would be responsible for generating such a document, though reference has been made to the disassembly plan guidelines prepared by SEDA (Morgan and Stevenson 2005).

Document Name

Rather than a 'Disassembly Plan', this document may be more appropriately titled a 'Disassembly Information Record' (DIR). This is because information key to a 'Disassembly Plan' would be only a part of this document and depending on the scheme, the plan would vary in complexity and scope. In this case, only key information is provided as the build is not considered complex or of a scale.

Material Record

To enable a user quickly to establish the amount and nature of the reusable products in the building, a condensed material inventory or record has been created. This sets out the key information (Quantity, Type, Length, Number, Species etc.) This would be adapted depending on the project. This exists within the main report, with a full inventory of materials provided in an Appendix.

Expertise

The general contractor undertaking amendments or the disassembly contractor removing the whole structure, are assumed to be experts in construction and to have a familiarity with typical construction methods. Knowledge of sequential disassembly is assumed, and an overly detailed description is considered unnecessary. The construction drawings and specification documents will be included in the appendices, which ensures that adequate information on the structure is available. For very complex structures, a more detailed disassembly plan may be required.

Need to know information

As with the DfDR tool, it is essential that a designer can prepare information for DfDR as seamlessly and easily as possible, given the limited time and financial resources available for this topic. Therefore, only information that the contractor needs to know should be generated and included in the main body of any document. This will also reduce the pre-project research time for a contractor as only key information will be prepared.

Manual Amendments

Updating the DIR during the life of the building will be essential. Consequently, amending or updating the record should be as straightforward as possible and the likely process treated with pragmatism. As the potential success of a digital file being updated seems limited, the proposed record will be updated by hand. Should adaption be made, the relevant amount of material which is removed or added is inserted directly below the original quantities highlighted in the material summary. A full material inventory, if generated for proposed works, could be appended to the inventory appendix.

An outline DIR document is illustrated on the pages following, based on the modified design proposed in this case study. For the sake of brevity and due to lack of comprehensively developed design materials, the Appendices are listed but do not contain data. The structure of the document has been reconceived from the SEDA guidance as outlined in Table 3.5.

Table 3.5 Organisation of Proposed Sections / Actions for Disassembly Plan

Stevenson & Morgan (2005)	Proposed DIR
Statement of strategy for DfD	**Record Storage Instructions**
List building elements	**Project Details**
Specifications, warranties, manufacturers	**Expected Reuse Scenario**
Include service life	**Material Summary**
Identify best options (reuse, recycling, etc)	**Construction**
Disassembly Instructions	**Connections**
Up-to-date location plans	**Fixing Specification**
Optimum technique for removal	**Strategies for Adaptability, Disassembly & Reuse**
Equipment required, sequential processes, H&S	**Amendments to Disassembly Information**
Categorising, recording and storage	**Architectural Drawings & Specification**
Distribution of Disassembly Plan	**Engineering / Fabrication Drawings**
Continual revisions, re-issue at each handover	**Warranties**
Stored with legal deeds, H&S plans and Maintenance Plans	**Material Inventory**

Disassembly Information Record (DIR)

Project: Timber Frame Dwelling House
Location: Richview, Clonskeagh, Dublin 4 (former location of UCD APEP)

Amendments to Disassembly Information

If making changes to the structure, please undertake the following tasks if making relevant amendments to the building following the production of this disassembly plan.

- Append drawings and specification of works as built to this document in the appendix
- Adjust the material inventory in Section 2 with any materials removed or added.
- Ensure that the document is updated in all locations listed in Section 1.

CONTENTS

Record Storage Instructions

This document must be stored at the following locations and all updated at amendments.

- On site, in a secure location, with the Safety File
- With the building deeds
- Local Councils Database

Project Details

Location: Richview, Clonskeagh, Dublin 4

Description: Semi-detached Single-family dwelling

Site Description: Brown field site (former location of UCD APEP)

Date of Completion: September 2023

Architect: St. John Walsh

Engineer:

Main Contractor: Acme Construction

Timbe Frame Supplier: Bignum Timber Frame

Truss Supplier: TrussRus

Expected Reuse Scenario

After one service life (about 50 years +), the building panels will be deconstructed into its original elements (studs, sheets, battens etc.), transported to a merchant or another site and reused in construction for the same or similar purpose. The connections have been designed to allow for the decomposition of the planar components (Roof Truss, Wall Panels, Floor Panels) into their constituent elements (studs, rafters etc.). Where possible, these elements may be extracted in their factory dimensions and therefore allow for direct reuse.

Disassembly Plan Information

The expected disassembly sequence is Reverse Assembly, from the roof down to foundations. A crane or hoist will be required to remove the roof trusses and first floor wall panels to ground level for disassembly into their elements.

- Crane Required: max panel weight 800kg.
- Common hand tools required: Screw gun, Sabre Saw, Hammer
- Temporary works: Scaffold and temporary works will be required
- Specialist Disassembly Requirements; None

See information below on Construction and Connections.

Important; A detailed health and safety plan, with method statements for temporary works, for the disassembly of the structure must be prepared by the general or disassembly contractor prior to undertaking work on the structure as per the Health & Safety legislation at that time.

Material Summary

The total volume of timber base material in the building structure is 22.54 m³ including OSB products and battens. The summary below captures only solid timber, excluding 1.87m3 of roof and wall battens (44 x 44mm) which are not considered appropriate for reuse. Please see inventory in appendix for full details.

NB; All structural timber has been preservative treated using a high pressure / vacuum process (I.S. EN 15228:2009). The preservative used is Protim E406.

Type/Location	Section Size (mm)	Grade / Species	<1000mm			1000mm - 2349mm			Above 2350mm			Total		
			m	m3	no.	m	m3	no.	m	m3	no.	m	m3	no.
Rafter (Truss)	140 x 38	C16 / A / Spruce	0.0	0.00	0	0.0	0.00	0	317.4	1.8	45	317.4	1.80	45
Rafter (Tie)	140 x 38	C16 / A / Spruce	0.0	0.00	0	60.4	0.32	45	0.0	0.0	0	60.4	0.32	45
Joist (Ground Floor)	150 x 38	C16 / A / Spruce	2.0	0.03	2	3.8	0.06	3	189.5	3.2	39	195.3	3.30	44
Joist (First Floor)	225 x 75	C16 / A / Spruce	3.7	0.06	4	5.2	0.09	3	189.5	3.2	39	198.4	3.35	46
Framing (Internal Walls)	89 x 38	C16 / A / Spruce	0.0	0.00	0	33.6	0.40	16	289.4	1.0	120	323.0	1.37	136
Framing (External Walls)*	140 x 38	C16 / A / Spruce	114.4	0.61	269	136.3	0.59	82	759.8	3.5	256	1010.5	4.71	607
*incl. sills, lintels, rails												**2105.0**	**14.85**	**923**
ADDITIONS (DELETIONS)														

Any Material added or removed in works after the production of this disassembly plan should be recorded in this section by hand.

Exclusions: Products which contain OSB are not considered as being recoverable however as these have been screwed and no glue has been used, these elements should be easily removable. Battens (internal and external) are not included in the volume.

Construction

The building uses construction techniques typical with the time (2021). Where specific tactics have been used for DfDR they have been noted below in section. Drawings are available in the appendix.

External Walls	TF200 Thermo 9mm OSB3 38x140mm c16 timber frame 90mm PIR insulation Foil Airtight membrane 44 x 46mm Service Cavity Airtight tapes and mastic Gerband
Internal Walls (loadbearing and non-loadbearing)	38x89mm C16 timber frame 11mm OSB to racking walls on one or both sides; supplied with one side fitted for installation and services / insulation. 100mm Acoustic Insulation
Party Walls	9mm OSB3 to cavity side of each frame Twin leaf 38x89mm C16 timber frames with cavity between 100mm acoustic insulation 15mm Plain (A) and 15mm fire (F) plasterboard
Party wall Spandrels	9mm OSB3 to cavity side of each frame Twin leaf 38 x 89 C16 timber frames with cavity between 80mm Rigid PIR to bottom 400mm 15mm Plan (A) and 15mm fire (F) plasterboard
Upper floor	18mm OSB3 225mm x 45mm Solid Joists 100mm Acoustic Insulation FCM 750 airtight membrane for floor wall junctions
Trussed Roof	Tiling battens Roofing felt breather membrane Cut Truss Roof, generally Rafters & Joists 140 x 38mm 400mm thermal insulation Vapour control foil 44x64mm service cavity

Connections

Part	Junction	Fixing Type	No. or Centres	Tool Required
Roof Battens	Battens / Truss	Screwed	400 c/c	Screw Gun
Roof Trusses	Truss Members	Wooden Nail -see description	at Connections	Sabre Saw
Eaves Junction	Truss / Wall Plate	Screwed w. Galv Truss Clip	8 no. / Truss clip	Screw Gun
Ceiling Service Cavity	Battens / Ceiling Ties	Screwed	400 c/c	Screw Gun
General Wall Panel Framing	Stud to Rail Connections	Wooden Nail – see description	400 c/c	Sabre Saw
Party Walls	Spandrel / Party Wall	Screwed	150 c/c	Screw Gun
External Wall Panels	OSB Sheathing / Stud Frame	Screwed	150 c/c	Screw Gun
External Wall Panel	Wall Panel / Wall Panel	Screwed	150 c/c	Screw Gun
External Wall Panels	Wall plate	Screwed	400 c/c	Screw Gun
Interior Load Bearing Walls	OSB / Stud Frame	Screwed	150 c/c	Screw Gun
Interior Non-Load Bearing walls	Stud to Plate Connections	Wooden Nail - see description	400 c/c	Sabre Saw
First Floor Deck	OSB Sheets / Solid Joists	Screwed - See description below	150 c/c	Screw Gun
	Joist / Header	Wooden Nail - see description		Sabre Saw
Rising Wall Connection	Wall Plate / Concrete rising wall	Screwed	600 c/c	Screw Gun

Fixing Specification

General Screw

Producer	Würth
EAN	XXX
Würth-No.	0123 42 70
Thread diameter d1	4.2 mm
Length total Ls	80 mm
Head diameter dk	8.1 mm

Soleplate Anchors

Producer	Rawl Plug WHO Screw
EAN	XXX
Thread diameter d1	7.5 mm
Length total Ls	112 mm
Head diameter dk	10 mm
Partial thread length LgT	
BIT size T	

Wooden Nail

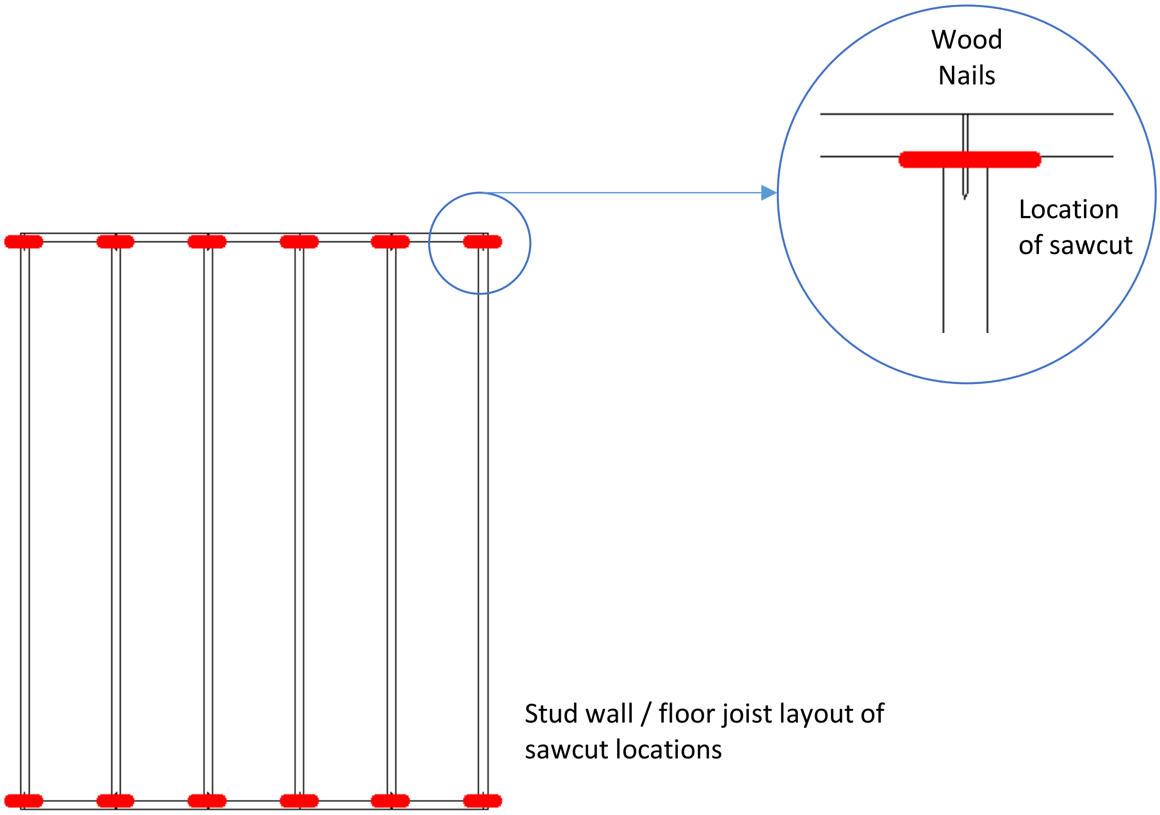
Producer	LIGNOLOC
EAN	XXX
LIGNOLOC-No.	XXX
Material	Compressed beech wood
Thread diameter d1	4.7 mm
Length total Ls	90 mm

Strategies for Disassembly and Reuse

Use of wood screws at stud rail junctions

Tool – Sabre Saw

Wood nails have been chosen in locations where the direct reuse of a element may be compromised by the location of a screw penetration. This will allow a future wood nail or metal screw be used in the same manner with no risk of aligning with the previously formed penetration. There is also no risk of metal fixings remaining in the timber.



No glue between OSB Deck and Joists

Tool – Screw Gun

To allow for disassembly, no glue has been used between the OSB Deck and the floor joists. The T&G deck may be removed using a screw gun following removal of the walls at first floor level.

Primary strategies for Flexibility & Adaptability

Joists to rear span from party wall to side wall to enable extension to the rear.

- Circulation allows for division of front room for office purposes.
- Refer to material inventory at the outset of disassembly.
- High quality drill bits should be used when deconstructing this structure to avoid damage to screw heads. The drill should be set to screw mode.

Appendix A: Architectural Drawings

Appendix B: Engineering / Fabrication Drawings

Appendix C: Warranties

Appendix D: Expanded Material Inventory

4 Discussion and conclusions

Residential buildings in Ireland have long been constructed of load-bearing masonry with structural timber use limited to intermediate floor joists and roof structures. Less than 1% of residential construction was built using a timber load-bearing structure prior to 1990. The growing phenomenon of timber platform framing in Ireland in the last 30 years has increased the share of this construction type to a current 27% of residential new builds (CSO 2020), mostly using prefabricated 2D wall and floor panels. Despite this surge of interest in timber construction, presumably on environmental grounds, the current predominant end use of timber being recovered from all buildings is downcycling into wood chip-based products or incineration for energy rather than reuse.

Given Ireland's modest, albeit growing, forestry cover and therefore limited structural-grade timber stock, this ever-increasing share of timber use in residential construction has already begun to put considerable pressure on timber supplies. Hence the need to reconsider the fate of structural timber coming out of current and future building stock, as an alternative supply for this growing timber market in Ireland. Our ambition in the current case study was to identify the potential for reuse in the current design and improve the recovery rate in a new design modified on the principles of DfA, to extend the service life of the building, and DfDR to maximise recapture and reuse potential.

4.1 Improvements to Current Design

Though the team had more than one prefabricated timber-framed house design to choose from, the Reflect 140 Semi-detached houses by Cygnum Timber Frame were considered emblematic of a standard mid-sized house type in Ireland, so held the most potential for reconsideration. Although the Cygnum design is constructed of prefabricated 2D wall and floor panels, so could have been analysed under a scenario of reusing these panels as other case studies did (UK, Sweden) our analysis considered the disassembly process from the perspective of the ultimate end-of-service life of the panels when they would be disassembled into material components.

There are distinct advantages to the current design in being prefabricated, as factory assembly generally produces less construction waste and significantly speeds up onsite construction time. There is also potential to reuse the wall panels and roof trusses a second time as-built, as is suggested in the UK and Swedish case studies, though Cygnum recommends against reusing floor panels due to the uncertainty of the service life of I-joists.

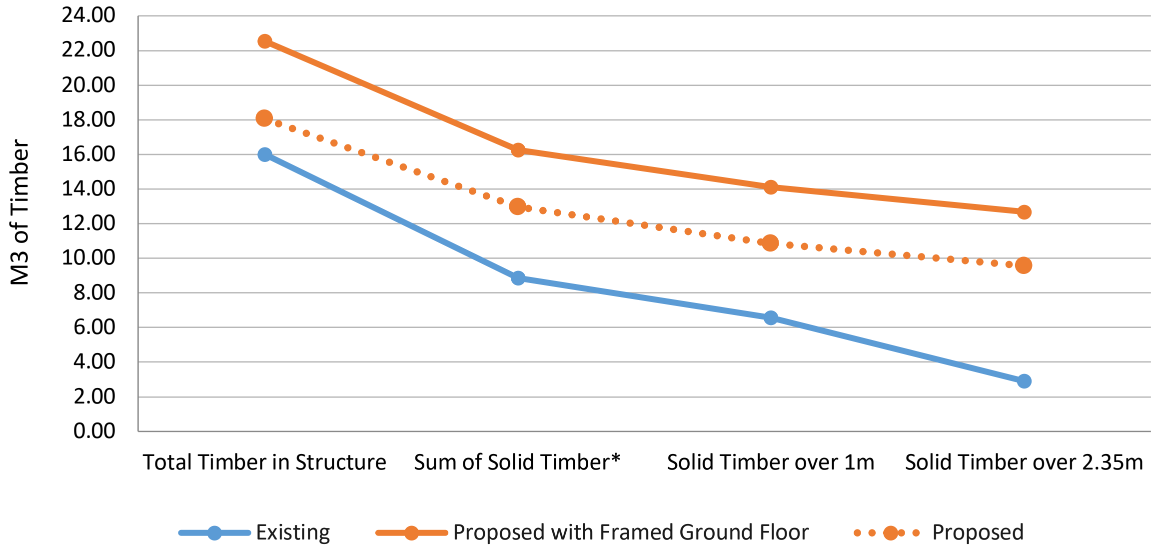
There were, nevertheless, several potential obstacles to the recapture of timber for a second use identified, principal among them the use of nails, driven in by nail guns, which are extremely difficult to remove. This would result in damage at panel-to-panel connections during deconstruction and inevitably lead to the discarding of the last 100mm of studs or joists to remove embedded nails, leaving lengths less viable for reuse. Equally problematic was the glue used in securing subfloor OSB to joists, effectively rendering them impossible to separate for reuse. The layout of the current design also resulted in not only a lack of long-term adaptability, particularly apparent in the choice of roof truss which restricted use of the attic space, which limited the service life of the building. The layout also resulted in a high degree of variability in the lengths of structural timber used, particularly in floor joists, which would limit the market available for their reuse.

The modified design addressed these obstacles through the application of principles for DfA and DfDR. The layout of the house was reconfigured on DfA principles to increase the efficiency of floor area use; allow for adaptability in use including occupation of the attic space using a cut-timber roof system; organised plumbing services for more effective use and simplified maintenance; and proposed a system of hinged wall panels to facilitate the maintenance and replacement of services.

The improved, more adaptable planning also served DfDR principles by rationalizing the joist layout to achieve standardized, full-length sizes use to minimise waste; replacing I-joists with solid timber joists that could be reused on recovery coupled with the elimination of the glue used in the subfloor assembly; and replacing nails with a combination of wood nails and screws to facilitate disassembly and ensure that joists and studs are recovered undamaged at full length to maximise their reuse potential. Though wood nails would be inappropriate in many connections, as they could make disassembly more complex, the impact of their strategic use in joist, stud, and rafter connections, where they are easily sawed, could be substantial to the ultimate reuse value of these elements as they would remain effectively solid wood composites without the difficult honeycombing at their ends which would otherwise occur.

The resulting estimated ultimate recovery rates from the original Cygnum design to the modified design speak to the efficacy of these limited changes to the project (Chart 4.1). This is further improved when the ground floor concrete slab of the original design is replaced with a timber-framed suspended floor. This not only increases the amount of solid timber recoverable from the design, but also simplifies access to services running under the floor joists. The rationalisation of the framing, specification of solid timber joists and the use of wood nails considerably improve the amount of solid timber recovered from a house of the same floor area as the original Cygnum design.

Chart 4.1 Recovery Rates of Structural Timber in Cygnum vs Modified Design and Modified Design with timber-framed ground floor One House only



There is clearly an opportunity here to maximise the use of solid timber, and its long-term carbon storage potential, in a design modified to extend a building's service life through adaptability with a final recapture of high value timber (>2.35m) at remarkable rate of 78% of total solid timber used for structural purposes.

Deconstruction Plan

The Disassembly Information Record (DIR) proposed builds on previous guidance from SEDA (Stevenson & Morgan 2007) but clarifies the ordering of information and expands the strategy statement to highlight DfA strategies for flexibility and adaptation, a crucial element to circularity. It also offers a degree of flexibility in ordering the document, to attend to the peculiarities of each project, and creates a simple and concise main document that addresses both the time constraints of the architect preparing the document as well as the prior knowledge of the contractor.

Critically, the DIR is considered as a hardcopy document, rather than a digital document linked to the BIM documentation that underpins the Material Inventory. This is a conscious departure from current research trends that exploit current and evolving digital technologies. The rationale for this is the inability to predict future digital technological trends in 50 years or more, when the building may be disassembled. By keeping the document hardcopy, the inevitable necessity of storing and updating digitally formatted data every few years is removed. This format also allows for handwritten amendments to be made by owners when the building is adapted or changed during its service life, with no need to access specialist models, software, and hardware.

Case Study method

The case study method, as defined for this project, provides a useful structure to follow in analysing a pre-existing design for potential improvements in DfDR. It did not specifically address DfA principles, which our team considered critical, so it was evolved to accommodate these issues. Also, the case study method only addresses a protocol for assessing a pre-existing design. To support decision making on a new design the Decision Matrix, developed as part of this study, holds more promise to educate designers on first principals of both DfA and DfDR and define specific strategies and tactics to use. The indicator system, also developed on this project, helps to assess the success of the design strategies used from the Decision Matrix.

The comprehensiveness of the analysis and overall success of using this case study method is very dependent on the team composition. Our team of architects approached the analysis from an architectural perspective, with guidance regarding spans and sizing drawn from the Eurocodes. We had the opportunity to consult with Cygnum engineers on their design, to better understand its construction and potential for reuse. However, having an engineer on our team for the modified designs would have been useful for a more comprehensive and accurate assessment. Viability of proposed improvements was likewise influenced by the knowledge base of the assessors, both in terms of construction and deconstruction methods, and would be facilitated by the engagement of a demolition contractor for specialist expertise, which was unavailable.

4.2 Limitations of Analysis

The digital modelling of both the original Cygnum house and the two proposals in BIM allowed for a reasonably accurate capture of a material inventory of structural wood-based products for comparison. However, the solid timber designated as longer than 2.35m was measured as 2.347m and above, to address minor modelling errors. Blocking within floor framing was not modelled for any of BIM models, so represents an undercount of solid timber under 1m in length. None of the models were fully developed for internal and external finishes, so the proposal for hinged interior wall panels to allow for service access was not fully resolved to account for fire-ratings or material type. This would require further research and development, so these panels have not been included in the material inventory.

The recapture rate of 72.1% for all timber-based materials remains an undercount, as many timber-based materials in a building are not structural (flooring, windows, doors, skirting boards) or have, for simplicity, not been included in the current analysis (stairs). Many of these items, particularly doors, windows, and flooring, if undamaged and of solid timber, already find markets in the architectural salvage trade. However, there is a lack of reliable research on how much these elements could account for as a proportion of the timber encapsulated in a house.

The service life of products, such as I-joists and OSB, has been insufficiently documented or, perhaps, researched. This led Cygnum to the conclusion that I-joists would not have second use, and for our team to decide the same for OSB sheathing and subfloors. It maybe that these products could be reused, if carefully disassemble, but it requires evidence from manufacturers to prove this.

The premise behind using wood nails for stud wall assemblies, joist framing and roof framing was to avoid the honeycombing that occurs in these structural members which reduce their reuse value. Due to constraints in using lab facilities during the pandemic of 2020-21, lab tests to determine the ease of cutting these joints easily and fixing them together a second time using wood nails were not undertaken.

4.3 Conclusions

The use of careful analysis to identify obstacles to disassembly and posit solutions has delivered a similarly scaled semi-detached house that encapsulates a greater amount of timber, improving the carbon storage potential of the building. Through careful planning with a view to adaptability, rationalisation of framing and of service runs, and the strategic use of wood nails and screws, a design was developed that facilitates a far greater recapture rate (74%) of solid timber in sizes that are viable for reuse.

There were several issues which became clear during this analysis. First is that a careful reorganization of a plan to allow for adaptable living spaces can be coupled with a similar rationalisation of framing to minimise construction waste and maximise recovery lengths for reuse. Second is the value of a broader team of specialists, including contractors, engaging at an early stage of a design proposal, to better understand and address the difficulties that may be encountered on disassembly. Third, that a clearer, more objective measure of reuse potential is required, as measuring the cubic volume of material, or the weight, offers little guidance on how much material would truly be viable for reuse in construction. In our study we selected 2.35m as a definition of the minimum high value length for a solid timber element, based on conventional floor to ceiling heights in Ireland. This is not to suggest that shorter elements could not be reused, rather than recycled, but are far less likely to find a viable market. This measure would vary by country and by construction type.

Finally, it became apparent that there is a need to consider the entire life cycle of a building, to its final disassembly into individual material components, even for prefabricated panel assemblies. Looking across the case studies it becomes apparent that recovery rates for houses built of factory assembled floor and wall panels can be very high for a second use given appropriate connection details between panels. But how easily the panels can be disassembled into material components is necessary to consider as well, to ensure that we capitalise on recovery rates further into the future, which the current case study goes some way to address.

5 References

CSO. 2020. Available: https://www.cso.ie/en/index.html. [Accessed].

DEBACKER, W. & MANSHOVEN, S. 2016. Synthesis of the state-of-the-art. BAMB.

FOUNDATION, E. M. 2013. Towards the circular economy. Journal of Industrial Ecology, 2, 23-44.

ITFMA. 2020. RE: "Irish Timber Frame Manufacturers Association (ITFMA)" Type to WALSH, A.-S. J.

I.S. EN 1995-1-1:2004 & A1: 2008 & A2: 2014 & AC: 2006. EUROCODE 5: DESIGN OF TIMBER STRUCTURES – PART 1-1: GENERAL – COMMON RULES AND RULES FOR BUILDINGS. Dublin, National Standards Authority of Ireland.

I.S. EN 15228:2009. STRUCTURAL TIMBER - STRUCTURAL TIMBER PRESERVATIVE TREATED AGAINST BIOLOGICAL ATTACK. Dublin, National Standards Authority of Ireland.

LLANA, D., ET AL. 2020. InFutUReWood project 18CENForestValue1 – Step 1: Timber Products from Demolition and Current Reuse Report.

MORGAN, C. & STEVENSON, F. 2005. Design and detailing for deconstruction. *Scotland Environmental Design Association, SEDA Design Guides for Scotland*.

TFHC "timber frame housing 2002 consortium – Housing.gov.ie."

WOODSPEC. 2020. *Design Guidance* [Online]. Available: http://www.woodspec.ie/docs/Woodspec%20Final%20-%20Section%20A.pdf [Accessed].