Extending the Adaptability of Ty Unnos

Developing Re-usable Components using Welsh Softwood

Coed Cymru

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June 2015

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Contents

Introduction

The following report is prepared by Davies Sutton Architects and Mann Williams following a successful invited tender for design team services by Coed Cymru in March 2015. The study funded by the Rural Development Plan is to consider the technical feasibility of the use of 'Ty Unnos' Welsh engineered timber construction components for the construction of example 'standardised' buildings for three alternative applications; classrooms, light industrial and offices.

Preface

In 2006, the woodland management charity Coed Cymru invited the Design Research Unit Wales of the Welsh School of Architecture and a number of commercial and academic partners to consider the greater application of homegrown softwood timber resources in the construction industry.

The United Kingdom has over 680 thousand hectares of Sitka Spruce, accounting for approximately 50% of the total conifer coverage in the UK. In its native range of North America, Sitka spruce grows slowly to a great age. British spruce however grows much faster producing timber of lower density with heavier branching and larger knots. It is processed for a number of markets including fencing, wood fuel, chipboard and pallets but the most important commodity produced is carcassing timber which is machine graded to C16, the lowest strength class in general use.

Published in 2007 as a feasibility study, titled 'Ty Unnos – Sitka Spruce Housing', the investigation proposed that in order for a system of timber components to be applied generally by the construction industry it would need to adopt an innovative and radical approach to timber frame construction methods. The investigation found that although structurally graded C16 softwood- predominantly Sitka Spruce, is readily available within the Welsh supply chain and suitable for construction purposes, it was rarely used in modern timber frame construction which normally *'utilises higher grades of imported C24 or TR26 softwood. Although Welsh spruce has poorer structural properties than imported softwoods, it is its tendency to twist during drying that timber frame manufacturers cite as their reason for not using it.'*

Nearly 9 years on from this original feasibility study a number of projects and innovative construction methodologies have very successfully employed Welsh timber, including within modern timber frame panel systems, however there remains no mainstream commitment to the use of Welsh softwood over imported timber.

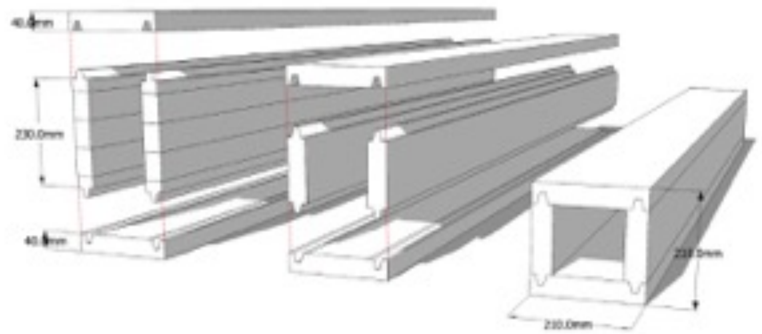
The 2007 feasibility study proposed an innovative approach to construction using a number of specifically designed prefabricated construction components. Although it was considered technically feasible for a system of components to be employed for the construction of most building types, the Project Team identified the application of affordable housing to be both technically appropriate and of essential need.

Ty Unnos feasibility study proposed a system of additive architecture with frames added or removed to meet the changing needs of occupants

PRIMARY STRUCTURE

Sitka Spruce Hollow Box Section

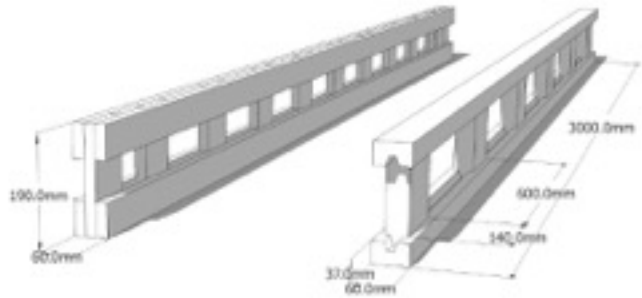
- Up to 6m floor span, 10m roof span.
- Infilled with recycled newspaper insulation.



SECONDARY STRUCTURE

Sitka Spruce Ladder Beam and Stud

- Up to 3m span
- Type 01: Glued and screwed C16.
- Type 02: Nail laminated 'falling boards'.



THERMAL ENVELOPE

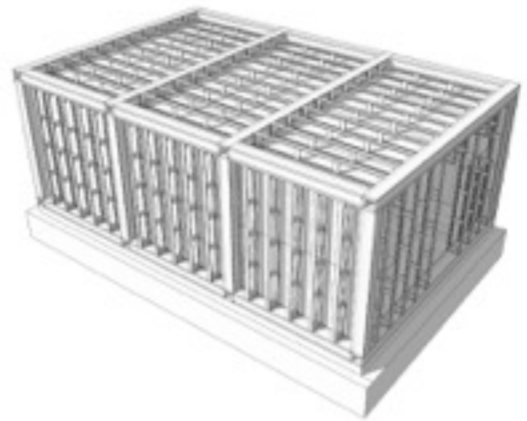
Dimensionally Coordinated Infill Panel System

- Up to 3m span.
- OSB based open panel system infilled on site using recycled newspaper insulation.
- Coordinated and interchangeable for walls, floor and roof.

VOLUMETRIC UNIT

Ty Unnos Modular

- Fully factory finished floor size house module.
- Code 4 compliant minimum envelope specification
- Suitable for low to mid rise housing applications.
- Module size limited by transportation requirements



Existing Ty Unnos construction components

Existing System Components

Generally known as the Ty Unnos System, the derived home grown softwood components take readily available standard sections of home grown Sitka spruce timber to deliver a range of engineered components using simple manufacturing processes.

The system comprises of two simply assembled engineered timber components; a hollow box section beam and a small section ladder beam. Although considered as individual construction components, development has typically focused on the application of these components as a whole building system, combined with plywood based frame connectors and assembled with internal and external sheathings of OSB or plywood to form naturally insulated infill panels.

The development team have undertaken a range of informal and formal structural tests to ensure components can be designed and employed for a wide range of structural purposes following the Eurocodes. The hollow section box beam can be used as a primary load bearing element in a post and beam or portal frame arrangement. It can clear span up to 6 metres in floors and 10 metres in roofs when used for domestic purposes. A number of ladder beam types have been tested and developed to use small section spruce and / or waste material from the box section manufacture. Ladder Beam Type 01 can be used as a floor joist with spans up to 3 metres and as a non-load bearing wall stud.

The components have been combined to form a number of off site fabricated systems that have been developed and tested for certification. This includes the Ty Unnos Modular housing system developed by Elements Europe as a fully off site fabricated volumetric housing system and the ETAG certified SHSS House by DRUw.

To date, home grown timber components derived from the Ty Unnos research and development project have been used for the construction of over 30 units. This includes housing, education, leisure and office buildings as both permanent and temporary buildings.

In addition to commercial application, a number of engineered components have achieved European certification for quality and performance in compliance with the Europe-wide Construction Products Regulation.

Project Brief

Housing has formed the primary focus for the project since its inception however use of the system for non domestic bespoke buildings represent perhaps the system's greatest success in application. This is due not least to the commercial pressures that have, and continue to, influence the delivery of housing in the UK during the period of the project.

Following the success of recent projects across the sectors, it has become apparent that the system's inherent performance characteristics and construction methodology offer great potential for the system to be applied to a range of non-domestic building types.

Following discussion with a range of public and private sector non-domestic building procurers and specifiers, Coed Cymru successfully applied for funding to assess the technical feasibility of employing the Ty Unnos construction components for the construction of classrooms, light industrial buildings and offices.

The project brief called for an architect led team to;

- Undertake the design of a deconstruct-able building system based on the Ty Unnos frame.
- Produce a series of plans of small buildings suitable for use as classrooms, offices, or small industrial units.
- Produce the necessary information and documentation for contract tendering, manufacture and build/ deconstruct/ rebuild.

Alongside the development of design based proposals, a manufacturing study will run in parallel providing the opportunity to prototype and test agreed outputs, with the ambition to realise a full prototype building from the proposed technical solution.

Developed Brief

Following discussion the project brief has necessarily evolved to capture and focus ambitions and ensure that the intended outputs are fully achievable within a tightly constrained project period.

In discussion with the client, the project team advised that the ambition to finalise proposals for 3 buildings including associated documentation for contract tendering, manufacture and build/ deconstruct/ rebuild was not achievable within the constrained project period. Subsequently it would result in critical steps in the development of an informed and fully resolved system being omitted or rushed.

The following report will subsequently focus on establishing the technical feasibility of adapting the existing Ty Unnos construction components to form a deconstruct-able construction system suitable for the construction of classrooms, light industrial buildings and offices. The project team will consider the existing system components and identify opportunities and threats to their applicability and adaptation, based on a number of concept design models for each building type. The project team will go on to identify areas that require development and present alternative solutions where necessary and feasible, for prototyping and testing. The project will conclude by summarising the further work considered to be required in order to develop a market ready solution.

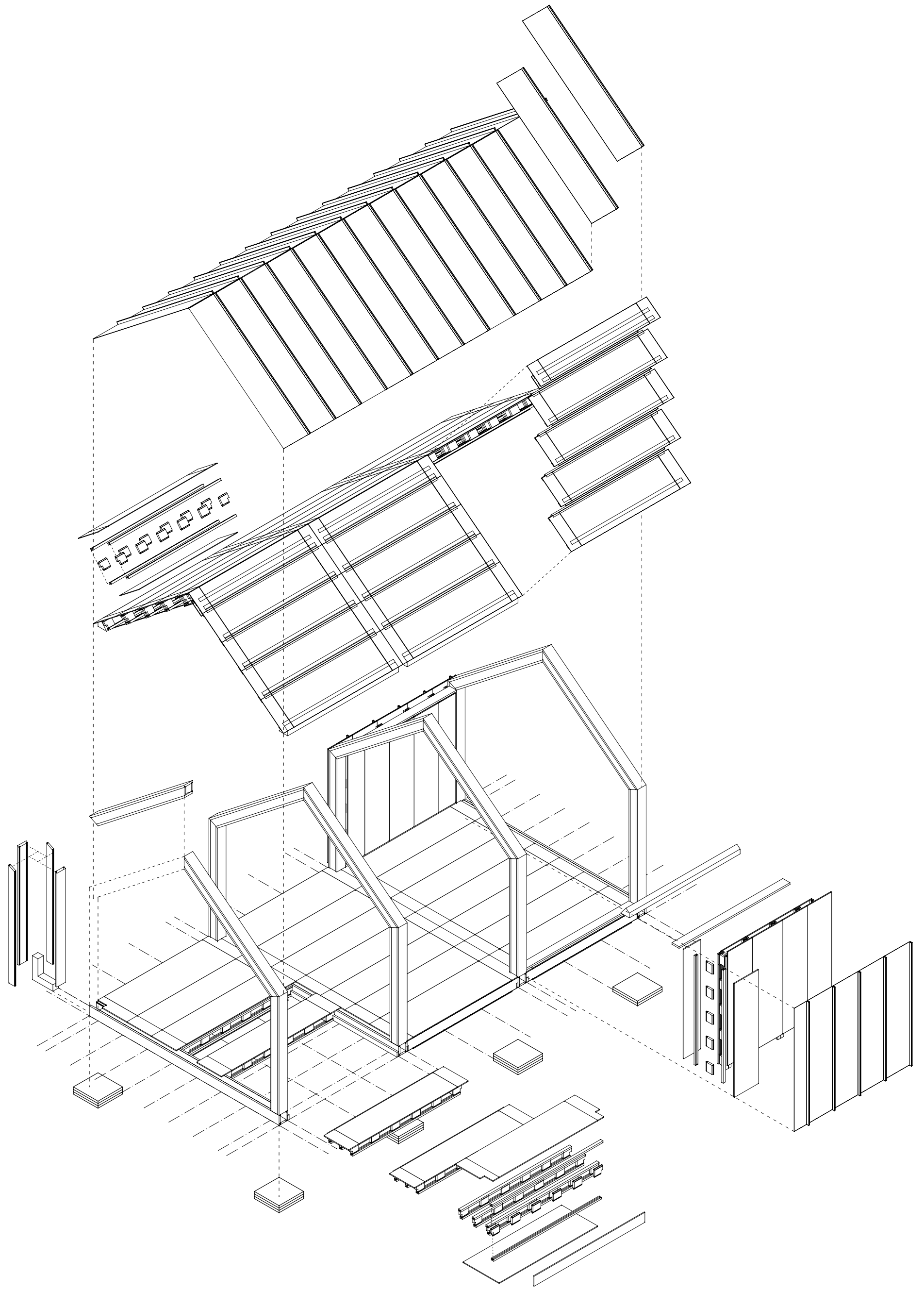
Performance Characteristics

In addition to the identified project aim prepared by Coed Cymru a number of system characteristics have been identified. The brief stated that the resultant system and building designs should;

- Be deconstruct-able,
- Be standardised wherever possible so that all parts of a deconstructed building can be reused,
- Incorporate very high standards of energy efficiency in use, in line with best practice, and meet current building regulations,
- Materials specified must be available from local sources where possible and demonstrate best practice in procurement.

Further characteristics have been present throughout the Ty Unnos R&D project including the ambition to;

- Utilise natural, recyclable and sustainably sourced materials that are readily available within the local supply chain,
- Employ manufacturing facilities, techniques and skills that are present within the existing Welsh timber industry
- Employ construction techniques that are appropriate to the construction industry in Wales, making use of existing skills, machinery and processes.



Permanent Quality / Temporary Life

The key determining characteristic identified in this developed project brief is the intention to be 'deconstruct-able'. Further analysis of this concept revealed the perceived opportunity for the Ty Unnos system to offer the concept of a 'Permanent Quality / Temporary Life' building.

In the context of this study, the concept of temporary life buildings has been developed following discussions with Gary Newman of Refab. In the context of a building industry which is recognising an increasingly prevalent trend for buildings to become obsolete long before the end of their designed life, Refab argue that is essential that building designers and procurers give much greater consideration to the end-of-life adaptability, recover-ability and / or recycle-ability of a much greater proportion of the original building.

There is a well established market for short life buildings, Portakabin being the market leader in this regard. The existing market tends to be based on volumetric solutions, with fully finished volumetric units delivered to site for the required life. At the end of its required life, units are recovered, and where possible refurbished for reuse, typically in its existing form. Although a generalisation, it is fair to suggest that the existing short life building market does not currently offer fundamentally adaptable building solutions, but rather volumes suitable in its base form for multiple functions.

During the course of the development project, the Ty Unnos construction components have been used for a range of short life projects. Pavilions and demonstration buildings have been constructed to test and prototype, demonstrate construction methods, or showcase Welsh timber. At the end of its functional use, the buildings are dismantled in to constituent parts, often capable of being manually handled, transported, stored and reassembled at another site, in another form.

The Smithsonian Pavilion first constructed in 2009 for the Welsh Festival at the Smithsonian, Washington as an open sided show stand, has been dismantled, adapted and reconstructed 4-5 times with very limited loss of performance, and with relative ease.

It is considered that intrinsic aspects of the Ty Unnos construction system , if developed specifically for this purpose, could present unique and exceptional levels of adaptability and recoverability, suitable for a broad range of temporary life building applications in the rural Welsh communities without compromising performance characteristics.

The Smithsonian Pavilion reconstructed as the Royal Welsh Showground Pavilion

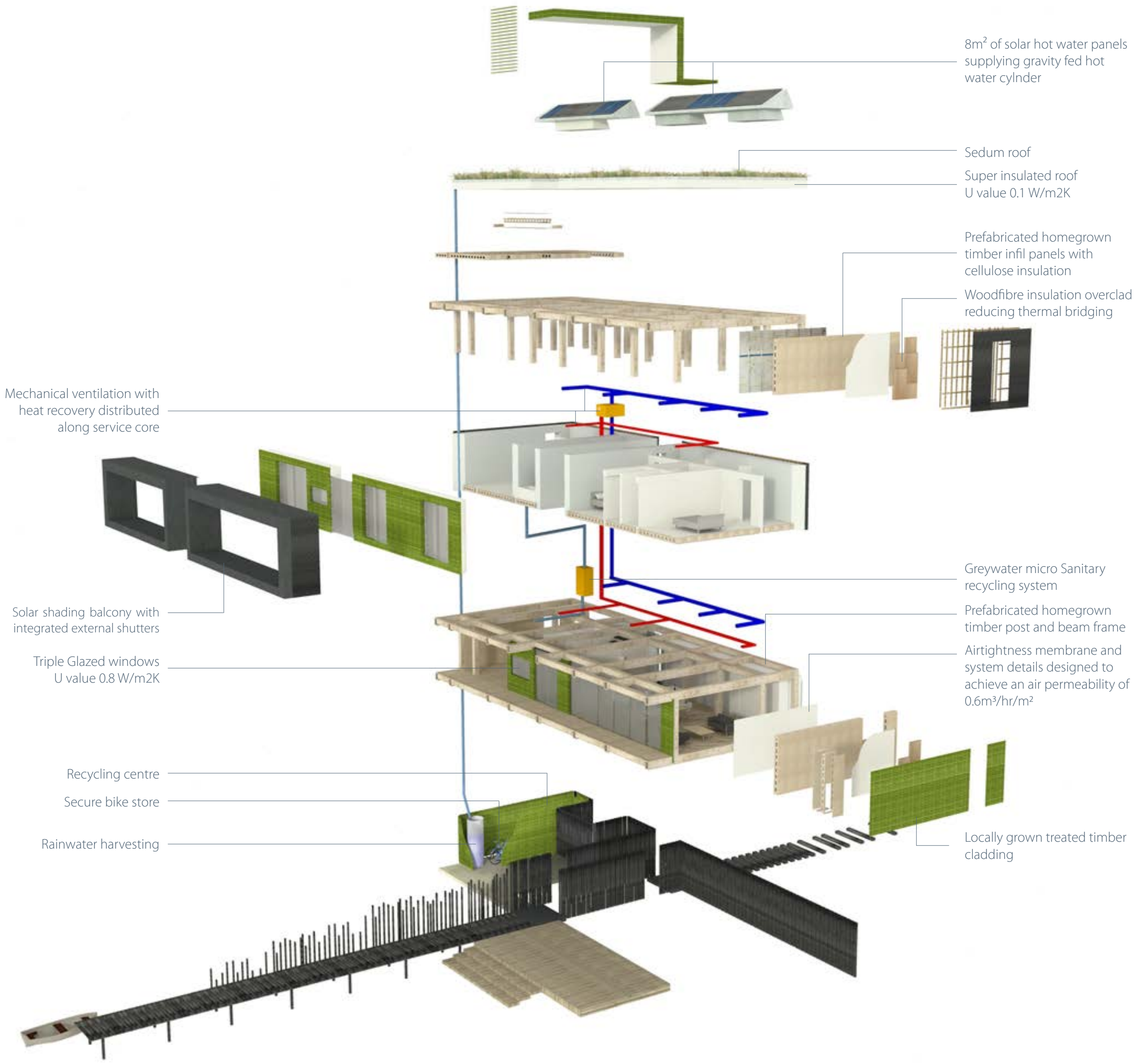
Methodology

In order to meet this brief, a number of strands of research will be undertaken.

- A series of design studies will consider the demands of applying the system components to the three building types of classroom, light industrial, and offices, considering space requirements and the implication for structural performance, thermal performance requirements, build-ability, standardisation and repetition. Investigations into standardisation will consider particularly the controls required on design decisions and rationale, in order for the construction approach to realise it's intended efficiencies.
- Technical design studies will consider the existing construction components and construction methodology to identify strengths and weaknesses that might enable or present a barrier to the adaptation of the system.
- Prototyping, including the construction of Coed Cymru's Royal Welsh Show Stand, and a series of concurrent manufacturing studies will provide data, including manufacturing cost and time, performance and build-ability of components.

The underlying theme will be the consideration of demount-ability ie the ability for the building components to assembled, disassembled and reused without significant loss or limitation to performance.

The study will briefly touch upon all aspects of the completed building, including internal and external finishes and services. However it is considered that the core of the system at this stage is the structural and thermal envelope, and it's necessary junctions to ground, floors, walls, roofs, and openings. The study will therefore briefly consider potential weaknesses or barriers that may limit the options for internal and external finishes and services and identify areas for future research and development.



The Jetty House passive house competition proposal by Designscape Architects

The Current System

A key factor in the efficient and cost effective delivery of buildings using 'Modern Methods of Construction' (MMC) is the relationship between the design process and the construction methodology. MMC typically represent highly alternative approaches to construction and by association require a design process that can recognise and adapt to these methods to make best use of them. This may impose limitations or controls on design, including frequently the demand for standardisation and repetition at the component or building scale. The earlier these factors are identified and used to inform the design process, the greater opportunity there is to realise the efficiencies offered by these systems.

Ty Unnos construction components are a fair reflection of this characteristic. The components, when combined as the existing system, represent a fairly radical approach and are distinctly different to the construction philosophy behind typical balloon or platform timber frame panel construction. The Ty Unnos 'system' has adapted the traditional philosophy of a post and beam frame, with large structural members acting to distribute the primary loads and a non loading infill providing a thermal fabric.

Throughout the course of the R&D project, the Project Team have been invited to tender for projects that have been designed up to and in some cases beyond RIBA Stage D / 4. Under these circumstances, it is rare to be able to offer added value to a project without sometimes significant adjustment of the design, including structural organisation, and dimensional coordination.

To date system components have therefore typically been used for the delivery of one-off bespoke buildings. These buildings have been designed and manufactured to order, frequently from project conception ie RIBA Stage 2-3. Although design principles have often been applied, there has been limited consistency and standardisation of the construction components and / or designs. These project have often been used to test and develop elements of the construction system.

Although successful in many instances the inflexibility of the system to extant designs, has restricted its application and limited the opportunity to realise the design and construction benefits associated with the system. Design elements include;

- Potential for low impact point foundations including screw piles and pads,
- A suspended insulated timber floor, providing the opportunity to 'touch the ground lightly', and making it suitable for sites with particularly challenging topography and ground conditions without need for significant groundworks,
- A primary post and beam frame enabling wide openings and open spaces limited only by the maximum span of box beams,
- An insulated roofline providing the opportunity for pitched or mono pitched roof spaces to be fully habitable.

Designing with Ty Unnos

Aim 1 - Design for Cost Efficiency

As discussed the system to date has typically been used for the delivery of one-off bespoke buildings, designed to order with limited consistency and standardisation of the construction components and / or designs. Open panels have been constructed to suit the size of openings, and frame geometries developed to provide the most cost effective solution to each building form. This has been essential when delivering single buildings as the key has frequently been single project cost effectiveness. However this method offers very limited opportunity to reduce the price of the system through economies of scale.

The development of this feasibility study has provided an opportunity to go back to basics to consider how best to, and at what scale to achieve standardisation.

Currently the cost of manufacture of the Ty Unnos components is deemed to be prohibitive to it achieving a broader market appeal. Although there are opportunities to deliver buildings using the components it is generally considered that cost represents the primary barrier to greater application, for both housing and classroom, office and light industrial applications.

With the remit of developing a strong and sustainable forestry for Wales, there is little ambition for the project team to drive the value of homegrown timber down to improve the cost effectiveness of the system. Rather, the project aim set out to increase demand in order to develop a supply chain capable of providing a consistent and sustainable supply of appropriately specified timber, providing added value throughout the Welsh supply chain. The cost of material is unlikely therefore to represent potential for a significant cost saving in the finished component regardless of scale of manufacture.

However in the event that an increased demand for system components can be stimulated, such as through the development of alternative markets, there are a number of opportunities for the cost of components to be reduced;

- Improved sourcing opportunities available from the supply chain due to increased and / or consistent demand for volume of material,
- Improved risk profile for manufacturers, enabling opportunities to invest in staff, training, plant, and facilities to improve efficiency,
- Improved manufacturing efficiency based on standardisation and repetition,
- Potential for continuous manufacturing and establishment of ‘on-the-shelf’ stock.

Key to realising these opportunities is the ability to design for standardisation and repetition.

Aim 2 : Design for Manufacturing Efficiencies

Improving manufacturing efficiency and thereby reducing the proportionate cost of labour and processing in the product is essential if cost of the componentry is to be reduced and a whole building solution become commercially viable for the identified sectors.

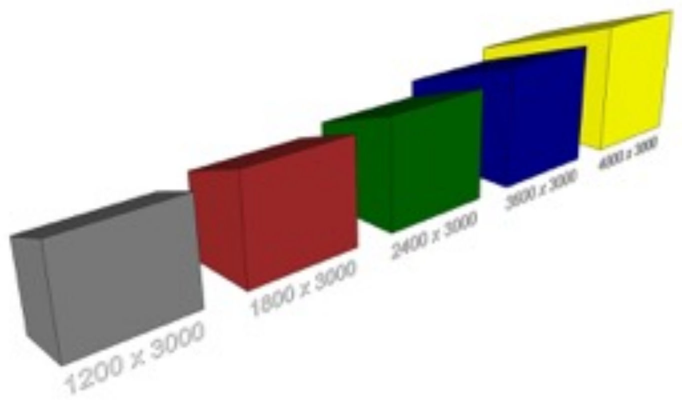
The existing system of components are relatively simple and limited in their degree of prefabrication. A post and beam frame of insulated box beams and columns is delivered to site, pre-cut and finished ready for assembly as a frame, either as a set of sticks, or combined as portal frames with connectors inserted and fixed. Infill panels are currently delivered to site as open panels, with external sheathing and structural members combined, ready to be inserted as floor, wall and roof panels. Further works are required on site to fix panels, install internal membranes, insulations and internal and external finishes.

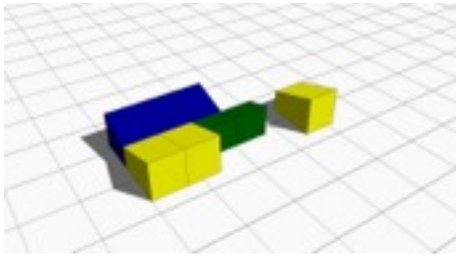
Modern Methods of Construction are defined as those which provide an efficient product management process to provide more products of better quality in less time. It does this by changing the methods by which we build, removing or altering on site construction processes, and in many examples, replacing it with off site manufacturing. In doing so, MMC, and specifically off site manufacture, enables greater control of waste, the integration of advanced manufacturing techniques and processes, implementation of quality control procedures, a broadening of the available workforce and critically the preparation of buildings in controlled factory conditions absent of the challenges associated with variable site conditions.

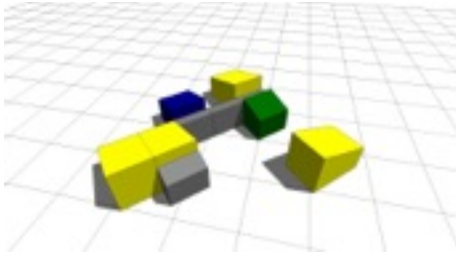
It is generally considered by the project team that the level of offsite manufacturing currently associated with the system components is not realising its full potential. There remains significantly more opportunity to realise the benefits described above, through increased prefabrication and further advanced and innovative construction components tailored to reduce on site construction time.

A primary ambition for the project team is to reduce costs associated with the manufacture of components. However this should not be confused with removing elements of prefabrication and re-introducing them to onsite works. In the development of a system of components the project should actively seek to advance prefabrication, and subsequently reduce on site works where there is a greater risk of delay, less control of quality, and Health and Safety associated risks. This will inevitably increase lead in time and costs associated with the system products. However if developed correctly, it has been demonstrated that this can be reflected in a subsequent reduction in cost and programme of works on site.

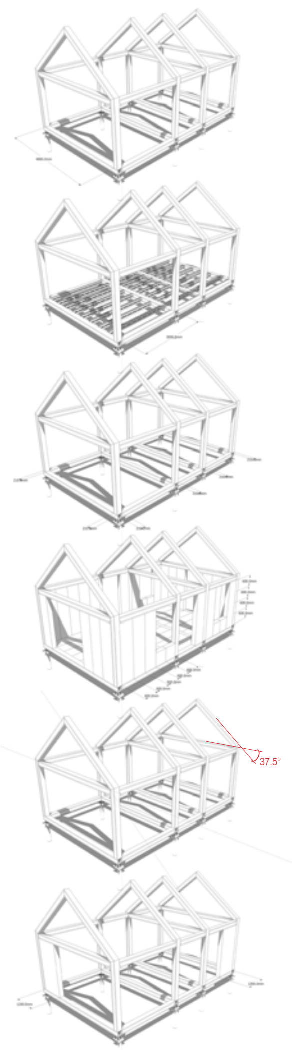
It is recommended therefore that in order to maintain pace with the MMC ‘industry’, any system of components should target advanced prefabricated components. This may include offsite assembled internal and external sheathings, vapour control and air tightness membranes, breather membranes, insulation, battening, service distribution ducts and internal and external finishes. It may also include integrated windows and doors.







Standardised room modules combined to form a wide range of house types



- A maximum primary structural span of 4.8m using a 270 x 210mm box section. (This can now be increased with the use of larger sections and more complex manufacturing processes that are beyond the scope of this study)
- A maximum secondary structural span of 3.0m.
- A primary post and beam structure is organised based on a 210 x 210mm or 270 x 210mm section size, determining an infil thermal envelope with 210mm thickness for internal and external walls.
- A dimensional organisation of 600mm increments between primary structural elements is employed in plan and elevation to determine the position of; primary structure, internal and external walls, floors, openings.
- Roof pitches are determined by spanning rafters integrated into the primary post and beam frame.
- A minimum requirement of diaphragm panels will be dependent on building form and site conditions. However Burroughs suggest a minimum requirement should be assumed as two 1.2 x 2.4m unbroken panels per floor with the most efficient location being the end bay.

Designing with Ty Unnos design rules taken from Affordable Self Build Housing for Rual Wales PhD study

The Proposed System

In order to realise these efficiencies, the project brief suggests an alternative approach and methodology be applied to the design of Ty Unnos buildings. This could occur in a variety of ways, a number of which have been trialled during the R&D project;

- The original Ty Unnos feasibility study proposed a system of standardised single storey modules drawing inspiration from Jorn Utzon's Espansiva system. Considered as a system for housing, standard fully designed modular rooms varying in sizes from 1.2m x 3.0m to 4.8m x 3m would offer spaces suitable for all requirements in a house, from entrance lobby to small bedroom to kitchen to living room. Modules would be restricted by size, form, materials, and roof pitch, with some flexibility permitted for the position and shape of openings. However modules could be combined with other modules in seemingly endless combinations to form a wide variety of house types.
- The TSB funded SHSS house study presented a pattern book of standard house types, which could be seemingly purchased 'off-the-shelf', tailored to maximise the efficiency of the system's constituent components, and realise associated design opportunities.
- The PhD *'Affordable Self Build Housing for Rural Wales'* proposed a set of design rules shown in the image opposite, including structural grids in plan and elevation, which if adhered to could enable an unlimited range of designs, all consisting of a limited and controlled palette of standard components.
- With Ty Unnos Modular, Elements Europe presented a range of standard single floor house volumes, fully finished off site with potential to combine with additional floor volumes and room modules to create a limited range of house types.

A primary consideration with each approach is the opportunity for design to be fit for purpose, including adaptability to site constraints including planning and context, design ambitions, and functional requirements.

When considering the alternative applications of offices, classrooms, and light industrial buildings, there is the potential to apply each of these models to the design of a system approach.

From top left clockwise : Sunesis pre designed primary school model, Portakabin volumetric stacked two storey school, assembling components of a Facit Home, Lilac ecological co-housing scheme by Modcell, a Modcell insulated wall panel, on site manufacture of Facit components using a CNC cutter.

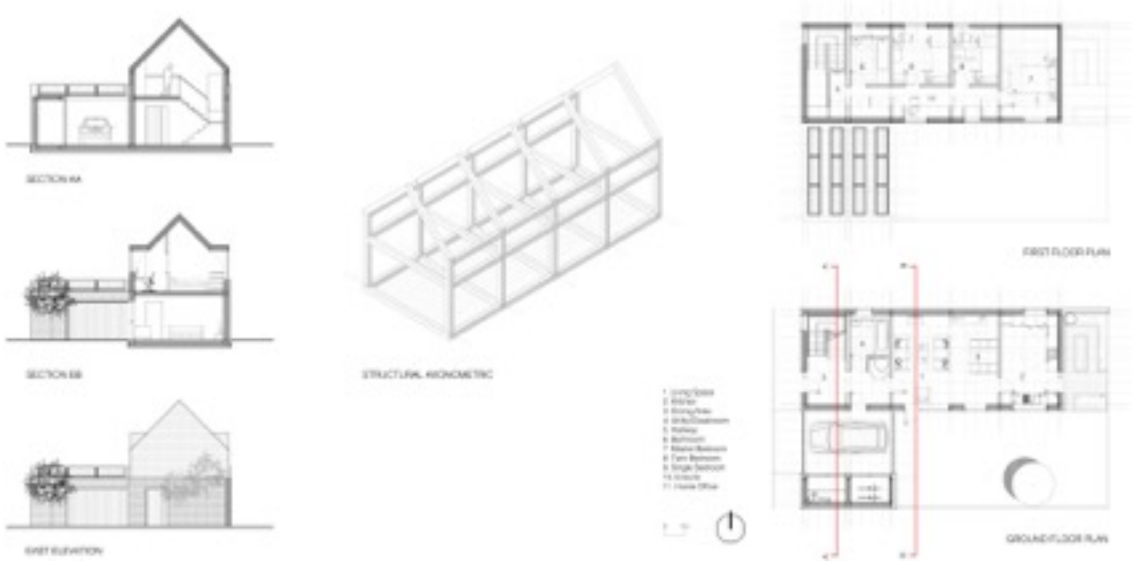
Scale of Standardisation

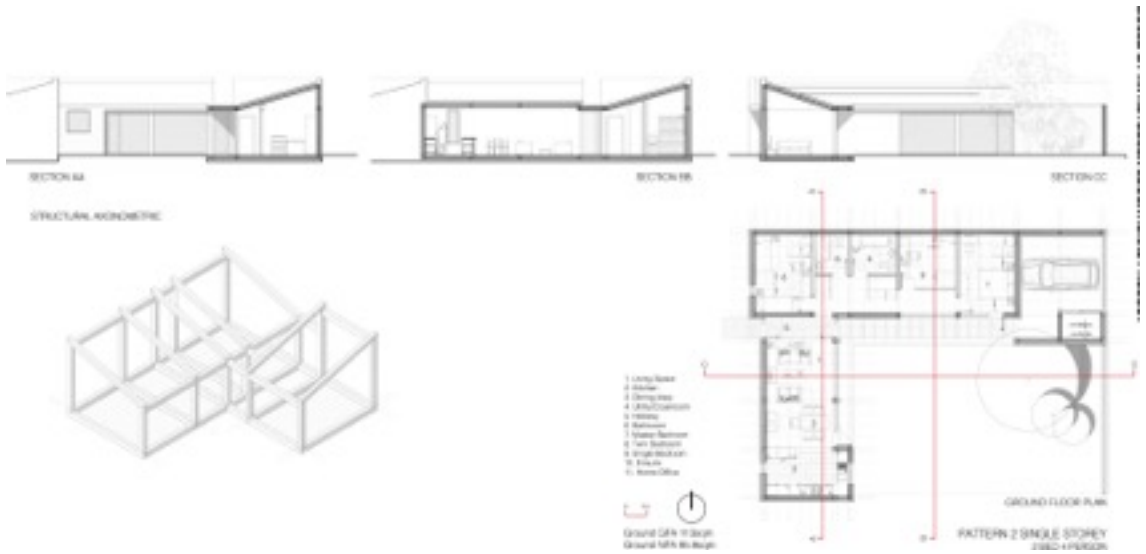
As the R& D project has progressed various studies have considered how best to standardise components and a number of methods have been proposed in order to control design and ensure construction efficiencies are maximised. The question is at which scale should components be standardised.

The market demonstrates a range of options from macro to micro;

- The Sunesis system developed by Wilmott Dixon and Scape is a range of pre-designed whole school buildings. Standardisation occurs at the building scale. This seemingly offers the opportunity to control cost at the whole project scale including all costs associated with consultants and delivery. The system does encourage standardisation and repetition of construction components however this appears to be of relatively low priority.
- Portakabin offer a range of standard room and multiple room buildings targeted specifically at school extension applications. In addition to standardisation at the space scale, these buildings adopt standard wall build ups, and standardised construction details.
- Facit Homes produce a plywood panel system for the construction of housing. Using precision CNC fabrication, bespoke designs are created as 3 dimensional models and broken down into interlocking plywood panels with standardised junctions and assembly details. Standardisation and repetition of panels significantly reduces the cost of design and fabrication and is encouraged wherever possible, however designs are highly individual.
- Modcell design and manufacture buildings using a straw bale construction system. The construction system combines cross laminated timber, straw bale and internal and external finishes to form advanced large scale wall panels. The system has a set of standardised, tested and certified construction details. Buildings are typically designed to order and panel designs generated from the standard set of details to suit the design arrangement.

Transporting full finished Ty Unnos modular housing units to development site





Initial Proposed System : The Volumetric Scale

The original project brief proposed that the design team generate a building or a range of standard buildings suitable for each proposed sector. This provides the opportunity to standardise, as per the Portakabin method, at the building scale. This presents a number of positive outcomes;

- Project associated consultant's fees can be dramatically reduced with multiple applications of the same design proposals,
- Cost can be strictly modelled and controlled,
- Manufacturing and construction associated efficiencies and quality can be tailored to known, standardised outputs,
- Supply chain and sourcing can also be tailored to known, standardised outputs,
- Designs as 'products' can go through a product development pathway to incorporate feedback, identify opportunities for improvement and efficiencies, and develop a commercial market.

However it should be recognised that aligning a proposed system with a limited number of standard designs may also present a significant constraint. Standardised volumetric solutions present an inflexible construction solution which offers limited opportunity to adapt and alter, both in regards to pre-construction and once in use. This includes;

- adaptability to site constraints and context such as existing buildings, topography and site geometry, planning concerns, access and environmental conditions.
- adaptability to functional requirements including pedagogical demands for classrooms, or scale, type and weight of plant and machinery for light industrial applications.

Revised Proposal : A Design Pattern Book

The broad potential demand within each building sector of classroom, office, and light industrial, suggests that limiting to a single or limited selection of fully resolved solutions for each sector may restrict the adaptability of the system. However a pattern book of building types which apply a standard range of components might offer a broader appeal, realising the efficiencies associated with standardisation and repetition, and maximising the integration of design opportunities associated with the construction method.

Type	Description	Gross Internal Floor Area / sqm
Office Type 01	Autonomous 4 person office with welfare facilities	36.5
Office Type 02	Autonomous 4 person office with welfare facilities and meeting room	47.0
Office Type 03	Autonomous 2 person office with welfare facilities	22.5
Office Type 04	Autonomous 5 person office with reception area, welfare facilities and meeting room	78.5
Office Type 05	Autonomous 1 person office with accessible toilet	13.5
Light Industrial Type 01	Autonomous small workshop with welfare facilities	35.5
Light Industrial Type 02	Autonomous scalable workshop with office and toilet	50.5 +
Light Industrial Type 03	Autonomous medium workshop with office and welfare facilities	56.0
Classroom Type 01	Autonomous single classroom for 30 people with accessible toilet, unisex toilet and breakout area	94.0
Classroom Type 02	Autonomous double classroom for 60 people with 2 accessible toilets, 2 unisex toilets and breakout area	170.0
Classroom Type 03	Autonomous single classroom for 30 people with accessible toilet, unisex toilet and store	88.5
Classroom Type 04	Autonomous 2 single classrooms for 30 people with accessible toilet and unisex toilet	155.0
Classroom Type 05	Autonomous double classroom for 60 people with 2 accessible toilets, 4 unisex toilets, urinals and breakout area	202.5

Table 1.1 : Area schedule of design pattern book

Design Investigation 1.1 : Design Pattern Book

Appendix A contains a selection of design 'patterns' considered to address a series of potential design scenarios for the three identified applications of classrooms, light industrial and offices. In parallel with design, prototyping and testing of componentry, the pattern book has been used to test and inform;

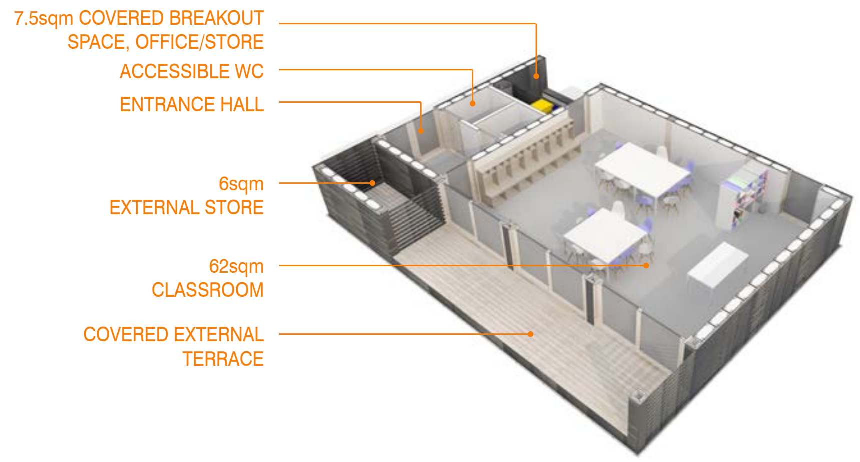
- design adaptability and flexibility associated with component sizes,
- minimum and maximum structural demands,
- structural efficiency,
- system appropriateness to alternative applications,
- and enable the development of indicative costs,

Each building pattern has been developed based on the following set of design controls;

- A standardised dimensional arrangement and setting out for the primary structural frame, based on a 600mm base dimension.
- A maximum primary structural span aligned with building types and load requirements,
- A maximum structural span for infill components, aligned with building types and load requirements, see investigations 6.2 and 6.4.
- A standardised arrangement for thermal infill panels based on a limited range of panel dimensions aligned with thermal performance requirements, based on the findings of the PhD study *'Affordable Self Build Housing for Rural Wales'* which recommends a 600mm base dimensions with derivatives of 300mm and 1200mm.
- A standardised arrangement for window and door elements, to coordinate with thermal infill panels.
- A restriction to roof form and pitch, perhaps limiting to a number of fixed roof pitch options.

Key documents and guidelines used in the preparation of this pattern book include;

- Building Bulletin 99 : Briefing Framework for Primary School Projects
- Building Regulations Approved Document Part L
- Building Regulations Approved Document Part M
- Department for Education : Standards for School Premises
- Department for Education : Area Guidelines for Mainstream Schools
- Workplace (Health, Safety and Welfare) Regulations 1992



Autonomous single classroom design proposal using Ty Unnos construction components

Findings

In parallel with the detailed development of componentry, the investigation has provided useful context to investigations. As expected it can generally be concluded that the design study has found system components to be adaptable and appropriate to the three applications. However there are a number of findings that require further consideration and may inform future design development;

- The primary box section structure is capable of achieving highly efficient long span spaces at logical structural centres thus making the structural system highly appropriately to large span spaces such as classrooms and light industrial units.
- Smaller spans achieve limited efficiency from the primary structural components.
- Floor loads on large span spaces however are demanding and subsequently a cost balance needs to be identified between additional foundation points and depth of floor structure.
- A 600mm dimensional basis enables a good flexibility in design however the addition of a 300mm and 1200mm wide panel as standard would enable further flexibility and efficiency, particularly in regards to the sizing of door openings.
- Floor to ceiling heights of less than 2400mm to suit standard board products will be prohibitive for large span spaces therefore infill panel systems should be based on panel lengths exceeding 2400mm in length.
- The number of individual components used to make up large structural openings are significant and therefore careful consideration needs to be given to construction tolerances.

Pad foundations and Ty Unnos frame connection as used at Castlepren lodges

Current System : Foundations

The current Ty Unnos system does not include a standard foundation form, this is largely due to the variable nature of foundations and site conditions, and the adaptability of the system to multiple foundation solutions. Foundation design is determined by two main factors; the bearing capacity of the ground and the depth at which that capacity can be achieved. This is extremely difficult to determine without prior knowledge of the site or site investigations. For demountable structures, conservative estimates will provide a suitable basis for calculation in most cases. It is also likely that demountable structures will be located in pre-existing sites, where information to support calculation may be available. Generally Ty Unnos structures are light enough to use shallow foundations even where the bearing capacities are limited.

The second key function of foundations is to resist wind uplift and overturning loads. This is generally resisted by the mass of the foundation or by some friction with the ground. For the Ty Unnos system this is often the limiting design condition for the foundations as the self-weight of the building is very low.

The three types described below are the most commonly used foundation solutions for previouss Ty Unnos projects.

a) Concrete Pad

Concrete pads are utilised to support individual or multiple columns spreading the load to the ground below. The size of the pad is determined by the load applied and the bearing capacity of the ground below, the lower the capacity of the ground the larger the pad. The arrangements of the pads will be dictated by the locations of the columns. The installation of concrete pads requires precise setting out in order to determine the locations of the columns before the frame has been set out. It also requires precise excavation, if the hole for the pad has been over excavated it will require more concrete to fill it or shuttering which will require more labour.

b) Concrete strip

A concrete strip foundation is formed by combining and elongating individual pad foundations to form a continuous beam. This is very similar to a concrete pad foundation but simpler to construct. Even though the setting out requirements are the same, the construction element is simpler and quicker than a concrete pad. For lightly loaded buildings with columns at close centres it tends to be an efficient design option requiring less concrete than isolated pads.

c) Concrete Raft

A concrete raft foundation is a single large foundation slab over the whole building footprint. It tends to be a relatively shallow foundation solution and efficient in poor ground conditions. The construction tends to be relatively complex and highly reinforced but this is offset by it forming the ground floor structure and the shallow depth.

Initial Proposed system

As part of this research project the foundations were reviewed and alternative options considered. The principle objective of this was to add temporary foundation solution options to the range available. These would be used for demountable structures such as site offices and classrooms constructed on existing hard landscaping or similar. The secondary objective of this was to start to develop a standardised foundation solution which can accommodate a range of soil conditions and site constraints.

Investigation 2.1 : Typical Ground Bearing Capacities

This investigation was a quick aid memoire of typical ground bearing capacities for a range of soil conditions and types. It was used for other investigations as a reference for the applicability of different foundation solutions.

Type of Bearing Material	Approximate allowable bearing capacity (kN/m^2)
Peat, muddy soil	< 50
Loose sands and gravels	75
Firm clays	75
Medium dense sands and gravels	150
Stiff clays	150
Dense sand	200
Rock	250 - 500+

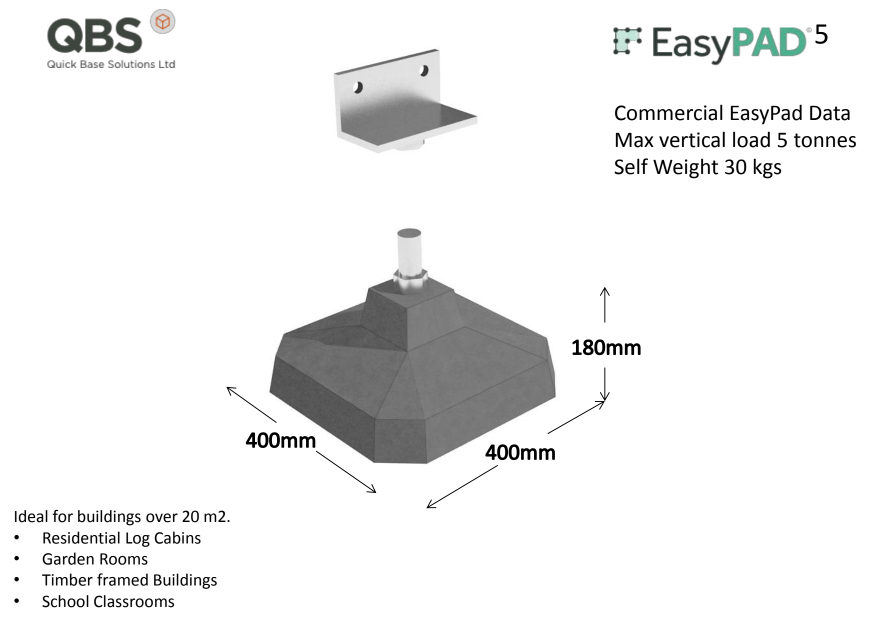
Table 2.1 : Typical ground bearing capacity

Investigation 2.2 : Easy Pad/ Jack Pad

This investigation was to assess the suitability of this as a temporary foundation solution and a permanent solution. These are a proprietary foundation solution formed from a profiled concrete pad with standard adjustable base connection. The profiled nature of the pads saves on material costs but reduces the self-weight of the pad and therefore its uplift resistance against uplift.

These are typically based upon a one storey building on a structural grid of 2-2.5m and has an approximate capacity of up to 50kN (5000kg). As with all foundation options this is dependent on ground conditions on site. In order to achieve the higher loading (50kN) on a site with poor ground conditions (loose sands and gravels) a pad of 0.6m^3 would be excavated and infilled with one of the following; low grade concrete, dry pack concrete or M.O.T Type 1 hardcore, this would be to enhance the grounds capacity and distribute the load over a larger area.

The main advantage of this type of system is that the pads are fully recoverable and prefabricated. This means the onsite foundation works can be limited to ground preparation and placing of type 1.



The Easypad adjustable foundation system

Screw Pile	Max Torque (kNm)	SWL (2.5) (kN)
60.3mm CHS	5.8	77
88.9mm CHS	18.1	181
114.3mm CHS x 5.5mm	22.8	228
114.3mm CHS x 8.3mm	31.0	310

Table 2.2 : Typical loads for mini piles

Diameter (mm)	Approximate allowable bearing capacity (kN/m^2)
100	50
150	90-100

Table 2.3 : Typical loads for helical screw piles

Type	Peak Loading (kN) unfactored	
	1 - Storey	2 - Storey
Office Type 01	120	195
Office Type 02	105	140
Office Type 03	125	210
Office Type 04	225	350
Office Type 05	70	120
Light Industrial Type 01	235	420
Light Industrial Type 02	105	160
Light Industrial Type 03	275	475
Classroom Type 01	210	325
Classroom Type 02	210	325
Classroom Type 03	150	225
Classroom Type 04	150	225
Classroom Type 05	235	365

Table 2.4 : Typical peak footing loads for pattern book building types

Investigation 2.3 : Mini Piles

This investigation was to access the suitability of Mini piles for permeant or temporary Ty Unnos structures on poorer ground. These can be constructed in reinforced concrete or circular steel sections. The installation of the piles requires a high level of accuracy and there is no tolerance for movement once installed. During installation of the piles some of the soil is removed which creates spoil on site which will require removal. Suitable when ground conditions are reasonably poor and the piles are used to reach rock or gravels at greater depths. This technique would require a sub-contracted specialist on site. In order to guarantee a certain performance some site investigations may be required. Piles will also generate reasonably good withdrawal capacities which can be used to resist uplift without reliance on mass.

In order to generate construction tolerance and provide an interface to the superstructure piles are typically terminated with an in-situ concrete pile cap at ground level. Due to the small nature of these piles it should be possible to minimise this or use a proprietary pre-cast solution.

Typical capacities – these are very dependent on site conditions but the values below are typically achievable, although it may require long piles.

For demountable structures piles can be a good solution because they cause minimal disturbance to the ground although they cannot be recovered. When the building is removed the piles can be cut off below ground level or possibly pulled out of the ground but would not be able to be re-used.

Investigation 2.4 : Helical Screw Piles

This investigation was to access the suitability of screw piles for permeant or temporary Ty Unnos structures on poorer ground. Helical piles are steel circular hollow sections with welded steel helical plates, which are fully galvanised. Usually segments are installed in 1-3m lengths. Similar to the mini piles the helical screw piles require much more accuracy during installation with no manoeuvrability once the frames are being erected. Unlike the mini piles the helical piles do not produce any spoil, these would be very useful on a site with contamination. In some cases they are removable and re-usable, this would be very suitable for demountable structures with similar site conditions. Quicker installation with no curing times as with concrete. Can be installed with hand held hydraulic solution for difficult access sites. Top connectors of each pile are versatile to accommodate all types of building supports.

Investigation 2.5 : Peak footing loads

This investigation calculated the peak foundation loads for a series of the proposed office, classroom and light industrial layouts shown in the attached pattern book. The results for this are shown in table 2.4. This shows that the magnitude of the loads for single and two storey buildings is well within the indicative allowable loads for the above solutions with the exception of Easy pad / Jack pad. If this type of solution is to be used additional ground floor support locations will have to be considered and a detail for sharing column loads between two or more pads resolved.

Sub-Structure

Investigation 2.6 : Bespoke Precast Pad / Pile Cap

This investigation was to consider the possibility of developing a bespoke precast foundation for Ty Unnos. This was discussed with Precast Solutions who manufacture precast concrete construction products. A bespoke foundation solution could build on the ideas behind the Easy and Jack pads but make them more suitable for the Ty Unnos system. This could include a number of features.

A standardised connection detail suitable for fixing to Ty Unnos columns which would make it suitable for buildings with or without a suspended ground floor. This could be a steel fabricated section with timber cheeks to fit inside the column.

The foundation could be constructed from woodcret. This has two distinct advantages in addition to providing a product to utilise wood waste generated as part of the construction process. The density of woodcrete is less than concrete meaning a pad of the size would be lighter and easier to handle. Woodcrete can be cut with a saw and can take a screw fixing, therefore the standard Ty Unnos foot detail could be used with coach screws replacing the concrete anchors. This would simplify construction whilst allowing construction tolerance and adjustment of the primary frame.

A potential uplift resistance solution would be to use a pad in conjunction with a stone filled gabion basket. The gabion basket could be placed in the ground and filled with compacted stone. This would then be tied to the pad to mobilise the mass of the stone against uplift. This would have the secondary benefit of increasing the bearing depth and further spreading the load into the soil.

The pad could be designed to act as a pile cap for a range of pile solutions to make it as versatile as possible. This would need careful consideration and detailed design but could enable a standard Ty Unnos footing detail to be developed.

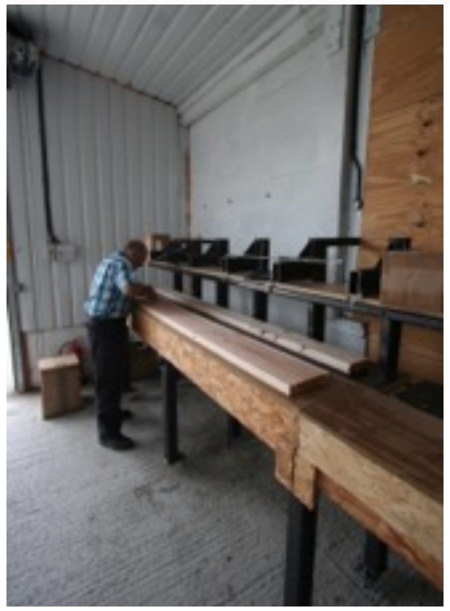
Conclusions

At this stage it is not possible to suggest significant changes to the foundation systems used for Ty Unnos. The investigations have shown a number of further options which could be considered in certain design situations. The most notable of these is the Jack / Easy pad which is a foundation type that has not previously been considered and is particularly suitable to the demountable building application.

Further Work

The development of a bespoke Ty Unnos precast pad / pile cap appears to have significant potential but would require significant further work. Producing a pre-cast concrete option would require design work to select and refine a suitable form for the pad and connection details to piles and the primary frame. A woodcrete option would be more complex as the material properties of woodcrete would also need to be investigated both in terms of structure and durability.

Primary Structure : Box Section



Assembly process of Ty Unnos box beam

Current System : The Ty Unnos Box Beam

The 210x210mm insulated hollow box section beam was the first product of the Ty Unnos research study and has remained a consistent and steady component in the project. Initial studies suggested standard box beam sizes of 210x210mm and 210x270mm could be manufactured from readily available standard stock sizes of C16 Sitka Spruce up to a length of 4.8m and in some cases 6m. The box beam geometry shown in drawing …. has remained consistent throughout the project and remains the standard profile manufactured by Kenton Jones Joinery.

The current box beams are manufactured from 4 solid timber sections glued together to form a hollow box. They are used for all aspects of primary framing in Ty Unnos buildings, including beams, columns and moment frames. They generally range in size from 210x210mm to 290x420mm with thicknesses ranging from 40mm to 70mm.

The current box beams are covered by Coed Cymru's ETAG 011 "Light Composite Wood-based Beams and Columns". This was undertaken as part of the Ty Unnos development and covered the design and performance of the box beams only. Any manufacturer wishing to commercially use the box beams would need to produce a factory production control manual and be audited by BM Trada.

This certification is relevant to the box beams individually and does not cover any of the beam to beam connections. It is relevant to service class 1 and 2 only. Only timber of grade C16 is permitted for the flanges and webs. Glues for the web to flange connection must comply with the Type II specification in EN301 or Type II of EN15425. The webs and flanges can be finger jointed along their length and the webs can be jointed in their length using a glued tongue and grove joint provided no section is less than 45mm tall. It is applicable to box beams in a range of sizes provided they satisfy the following:

- Width 180 - 350mm
- Depth 180 – 500mm
- Minimum void width or depth - 100mm
- Minimum web or flange thickness - 40mm

Generally, this covers all Ty Unnos box beams which have been used in previous projects. However to date, finger jointing has only been carried out by Cowley Timberwork for bespoke applications.

A range of typical beam sizes were developed previously in conjunction with Kenton Jones. The aim of this exercise was to develop standard beam sizes which made best use of the available materials to minimise waste. Some recent projects have shown this to be out of date and in need of revisiting.

Kenton Jones Joinery (KJJ) is currently the only consistent manufacturer of Sitka Spruce box beams, manufacturing within dedicated facilities in his workshop and showroom in Welshpool. KJJ, in conjunction with Elements Europe, have been validated, and maintain regular inspections by TRADA, to ensure an appropriate factory production control procedure in order to meet the agreed compliance for CE marking of the box beam products.

The current process for manufacturing the box beams is as follows:

- Timber is selected from stock, rejecting overly twisted sections and timber above a threshold moisture content.
- Sections are then cut to approximate length
- Web and flange sections are machined in a four sided planer to regularise the sections and mould the corner tongue and grove joints.
- The box beams are assembled by applying glue to the tongue and grove joints fitting them together and pressing.

- While in the press wood screws are installed at approx. 450mm centres.
- The beams are then removed from the press while the glue is still curing.
- Following curing the beams are treated as required and filled with Warmcell insulation if required.

This manufacturing methodology has been developed and adapted by KJJ from the original assembly method used by Coed Cymru in order to meet their ambitions for the product and maximise efficiency. A number of observations have been made by the project team;

- All box sections are prepared as finished grade components appropriate for exposing internally.
- Off the shelf graded Spruce is re-stacked and re-kilned by KJJ in order to ensure consistent moisture content and meet quality control requirements.
- Timber is then put through an additional visual selection process with timber rejected for wane, twist and defects.
- A four sided planer is used to square and profile each timber in a single process, also enabling non essential profiling such as the removal of arises etc to be incorporated.
- Box sections are glued and pressed, with screws installed during clamping to reduce time in the press and increase throughput.

KJJ currently manufacture box beam components on a project by project basis. Projects are grouped where possible to establish some continuity of manufacturing. Sourcing of materials will often be on a project by project basis however some speculation has been embraced to 'stock-up' when a supply is available, particularly when oversized and / or over length timber becomes available. KJJ do not currently manufacture any box beams for storage and stock. Lead in time can vary between … weeks and …. weeks.

Analysis of box beam manufacture

Manufactured on a project by project basis, KJJ has established a manufacturing profile which is well adapted to the delivery of bespoke one off houses.

- Materials are sourced to order,
- Cutting lists are prepared by consultants on a project basis,
- Lead in times are typically generous enabling time for sourcing, processing and manufacture of components,
- Labour is highly skilled and adaptable enabling multiple business and manufacturing streams to operate in parallel and ensure a full time employed labour force can be fully occupied on other tasks during 'down-time' for Ty Unnos projects.

In order to deliver the proposed advanced system it is generally considered that the supply chain would need to considerably increase its capacity and in doing so realise significant economies of scale to reduce the cost of components.

Initial Proposed System

There are three key objectives for the box beams under this research project,

a. to review the standard beam sizes,

b. to bring the potential for finger jointing techniques in to the manufacturing team,

c. to enable additional manufacturers to make box beams and identify and analyse opportunities for reducing manufacturing costs.

It is considered that a review of 'standard' box beam sizes is required in order to confirm the availability of timber sizes and minimise wastage. Although 270x210 and 210x210mm remain the basic box beam geometries, the variable and longer spans required to meet alternative building types will demand a greater flexibility from the box beam geometry. Historic feedback has suggested that although a wide range of appropriate homegrown C16 section dimensions are proposed as being available, sourcing these sections in reality is much harder to achieve. The aim therefore is to identify a table of standard box beam geometries, using readily available homegrown timber. In addition it is desirable to extend the range of square column sizes available in order to simplify construction detailing at building corners.

During the course of the study, finger joint cutting machinery has become available (from Cowley Timberwork). There is considered to be great value in the potential for finger jointing to become integral to the manufacture of box beams, most notably as a method of increasing box beam lengths beyond the available length of standard timber. Machinery has therefore been purchased in collaboration between KJJ and Coed Cymru, including training. Finger jointing trials will then be undertaken to assess the viability of using these to manufacture longer box beam lengths.

Following a Sell to Wales invitation to tender, a new potential manufacturing partner, Towey Projects, will be given instruction and assistance in tooling up to manufacture box beams.

Beam Reference	Finished Beam Size w x d	Flange External Size	Flange Machined From	Web External Size	Web Machined From
TU - BB1	290 x 420	70 x 290	73 x 300	40 x 300	47 x 300
TU - BB2	210 x 420	70 x 210	73 x 225	40 x 300	47 x 300
TU - BB3	290 x 360	40 x 290	47 x 300	40 x 300	47 x 300
TU - BB4	210 x 360	40 x 210	47 x 225	40 x 300	47 x 300
TU - BB5	290 x 330	70 x 290	73 x 300	40 x 210	47 x 225
TU - BB6	210 x 330	70 x 210	73 x 225	40 x 210	47 x 225
TU - BB7	290 x 270	40 x 290	47 x 300	40 x 210	47 x 225
TU - BB8	210 x 270	40 x 210	47 x 225	40 x 210	47 x 225
TU - BB9	290 x 210	40 x 290	47 x 300	40 x 150	47 x 150
TU - BB10	210 x 210	40 x 210	47 x 225	40 x 150	47 x 150
	180 x 180	40 x 180	47 x 200	40 x 120	47 x 125
	270 x 270	40 x 270	47 x 275	40 x 210	47 x 225
	140 x 140	40 x 140	47 x 150	40 x 80	47 x 100
	290 x 290	70 x 290	73 x 300	40 x 170	47 x 175
	290 x 290	40 x 290	47 x 300	40 x 230	47 x 250

Table 3.1 : Existing box beam sections

Investigation 3.1 : Box Beam Size Assessment

This assessment was focused on the efficiency of manufacturing the current ten box beam sizes from standard timber stocks and the potential to add beam sizes to the list. Timber for Ty Unnos is currently sourced from a number of sawmills but the largest contributor is Pontrilas Sawmills. Therefore the list of standard stock sizes from Pontrilas has been used to assess the current beams.

Box beams are manufactured from four pieces of timber, two flanges and two webs. These pieces are manufactured by regularising stock timber and cutting in a tongue and grove joint, the tongues are added to the top and bottom of each web and the groves are cut into one face of each flange. At present this is done using a four sided planer.

The table opposite shows 10 standard Ty Unnos box beam sizes with the flange and web external sizes and the timber pieces they are machined from.

This shows that generally the ten standard box beam sizes are not wasteful and that additional square sections could be manufactured without significant waste. The table does suggest that box beam sizes TU-BB5 – TU-BB8 could be increased in depth by up to 15mm without requiring larger timber sections.

Feedback from Kenton Jones suggests that 300mm wide boards are difficult to source, particularly 73 mm thick boards.

This would suggest that of the 10 sections, only TU-BB6, TU-BB8, and TU-BB10 are not as accessible as initially hoped. In conclusion, some minor adjustments are required to the standard box beam sizes and additional square sections are to be included. However consideration needs to be given to the specification of 300mm width box beams, with the need perhaps for increased lead in time, and/ or the compiling of a stock of 300mm width timber.

Investigation 3.2 : Finger jointing

In this investigation 4 No 8m long box beams were manufactured by Kenton Jones with finger joints in the webs and flanges. A report on the manufacture was produced by Kenton Jones and the beams were inspected following completion.

Some of the comments and conclusions from this relate to the standard box beam assembly and have been included in the box beam trial manufacture investigation. Only comments relating to the finger jointing have been included here.

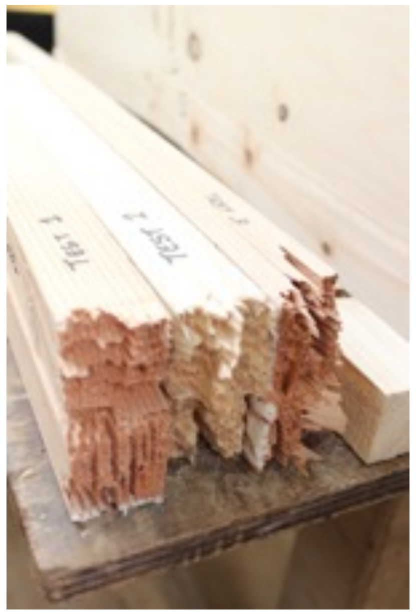
In total it took an additional 5 hours 30 minutes to finger joint sufficient web and flange timbers from 4.2m length standard sections, to make 4 no. 8m long beams. This works out as 20 minutes per finger joint (4 joints per beam gives 16 No in total). Other than an additional step to glue and combine finger jointed lengths, the manufacturing process described on page 19 was unaltered. Once glued and screwed, 8m lengths were found to be too heavy to manoeuvre manually by two people therefore a chain winch was installed locally within the workshop.

Generally, feedback from this process was positive. An inspection of the final product found there to be no loss in quality compared with a single section length, including in regard to straightness. It was observed that the finger jointing cutter is not ideal, as it is a bespoke machine designed by Cowley Timberwork to be very versatile and adaptable to different situations.

It was suggested that the finger joint cutting tools could be used in Kenton Jones' double end tenoner to finger joint standard board lengths quickly and efficiently. This would be possible for board lengths up to 3m. Assuming no reduction in the process time adding finger joints at 3m centres would cause an uplift from 12 minutes per linear meter to 38 minutes per linear meter but would allow beams of any length to be produced. This should be considered an upper bound as the use of the double end tenoner would reduce time to cut the finger joints. Currently approximately 13 minutes per linear meter was spent cutting the finger joints and 13 minutes per linear meter was spent gluing and assembling them.

From left to right : finger jointed 'L' type frame connectors, pre and post testing, finger jointed end to end connection following testing, finger jointed 8m long beams with chain winch






Investigation 3.3 : Box beam trial manufacture

In this investigation Kenton Jones and Towy projects manufactured 4 no. 3m long and 4 no. 4m long 270x210mm box beams each. The resulting beams were inspected and the respective organisations reported on their findings.

The beams produced by Kenton Jones were similar to previous beams produced and employed the manufacturing process described on page. As such they will be used as a comparison for quality, time and cost.

For Towy Projects, the investigation provided the first opportunity to produce a reasonable quantity of box beams. Prior to manufacturing, Towy were given a demonstration of the existing manufacturing process including the Coed Cymru pneumatic press. However after a trial assembly Towy identified concern with the limitation placed on the manufacturing process due to the single capacity of the clamping process and the required gluing time. This restriction has been mitigated by Kenton Jones by the installation of screws at regular intervals to clamp the timber whilst gluing however the additional cost and time associated with installing screws has been raised as a potential in-efficiency in the existing process.

In order to overcome this Towy trialled an alternative clamping process using 4 lengths of steel angle with welded threaded rod receivers. The assembly process was subsequently as follows;

- Timber flange section is laid flat of trestles with loose angle sections clamped to each long edge.
- Glue is applied to the tongue of both web sections and the flange in continuous even lines.
- Web sections are located within groove.
- Glue is applied to upper web sections and the upper flange and upper flange located and loosely located.
- Angle sections applied to upper edges and 16mm threaded rods located in welded receivers at 450mm centres.
- Bolts tightened using pneumatic or powered torque wrench to give even compression to predetermined torque of 58Nm.
- Sash clamps are used diagonally to ensure box beam is squared.
- Box beams remain clamped until fully cured.

The system of assembly takes approximately 10 mins once timber is processed. Towy have manufactured 4 sets of clamps with a maximum length of 4m at a cost of …., enabling 4 beams to be manufactured in parallel.

Findings

- Towy Projects advised of a number of issues sourcing both timber and glue for the investigation.
- Towy sourced 156 linear metres and rejected 44 linear metres, approximately 28% of the timber sourced.
- Towy processed tongue and groove using planer and spindle moulder requiring multiple passes. KJJ uses a four sided planer with all profiling completed in a single pass. Towy have advised that the purchase of a suitable planer would cost approx. £13.5k exc VAT and would result in halving the processing time.
- Towy advised that time records includes time for development of the beam clamp and manufacturing process.
- KJJ contacted a number of suppliers to source C16 Welsh dry graded softwood but found only Pontrilas Timber could supply to meet the timescale.

Primary Structure : Box Section

- KJJ sourced 134 linear metres with 19 linear metres of waste due to board length however no timber was rejected due to quality or moisture content. KJJ identified primary delays to manufacturing times include;
  - Setting up of machinery
  - Bent and twisted timber
  - Flange size - at 40mm flange thickness an 80mm screw is used during assembly, at 60 or 70mm flange thickness 120mm screws are used with high occurrence of screws wondering.
  - Beam length - 3 and 4m beams at this scale can be assembled by hand however large and longer beam section require mechanical lifting

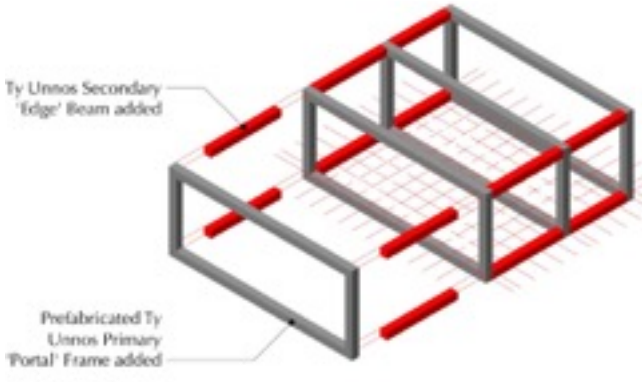
The table below shows a comparison of the beam manufacturing costs between KJJ and Towy. It is evident that within the manufacturing process there is significant cost associated with processing the timber in the costs of Towy. Whilst there are opportunities to reduce this cost, it requires significant capital outlay. KJJ has developed a processing methodology which is highly efficient and currently appears challenging for Towy to reach a similar level of cost. The development of the beam clamp however is an interesting development and would have a payback time of approximately 45 - 46 linear metres based on the saving in screws.

The study has reinforced observations that there is opportunity within the manufacturing process for further efficiencies to be realised by increased quantities and continuous throughput. Of particular note is the time required to set up machinery for processing timber which can take up to an hour to turn around.

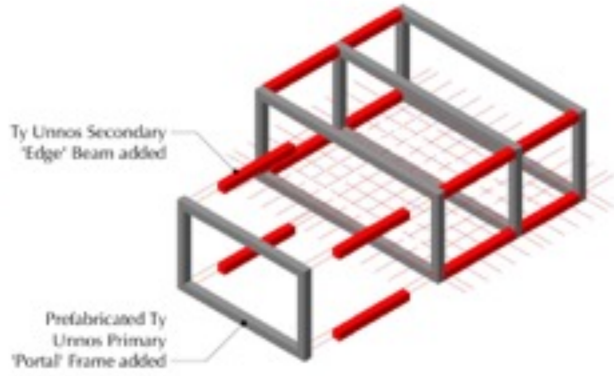
	Towy Projects			**Kenton Jones**		
	Total Cost	**Total Time**	**Cost per linear metre**	**Total Cost**	**Total Time**	**Cost per linear metre**
Timber sourcing	480	0.75	17.14	461.26		16.44
Timber processing	660	33	23.57	60	3	2.14
Jowat Glue	29	0.25	1.03	29		1.03
Glue + press	520	26	18.57	46.66	2.33	1.66
Screws				36.37		1.30
	1689	**60**	**60.31**	**633.29**	**5.33**	**22.57**

Table 3.2 : Comparison of linear metre-age manufacturing cost of box beam
Based on £20 an hour rate provided by Towy Projects

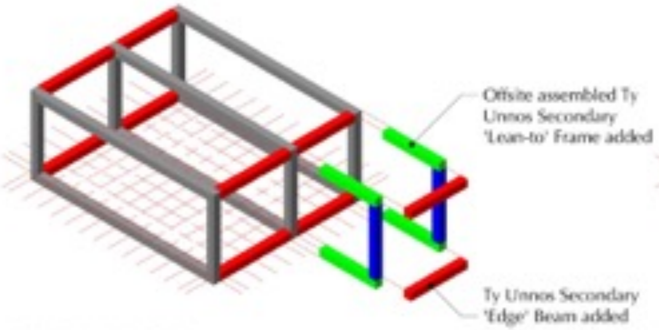
Primary Structure : Frame



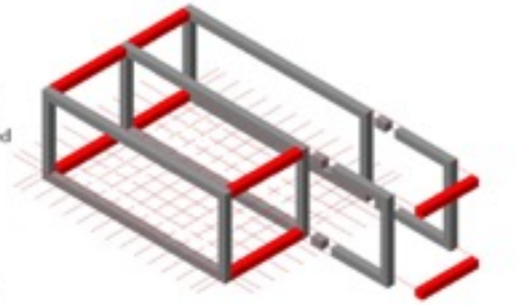
V 900.3 ADDITIONAL FRAME IN Y-AXIS As Current
SCALE 1:150 @ A3



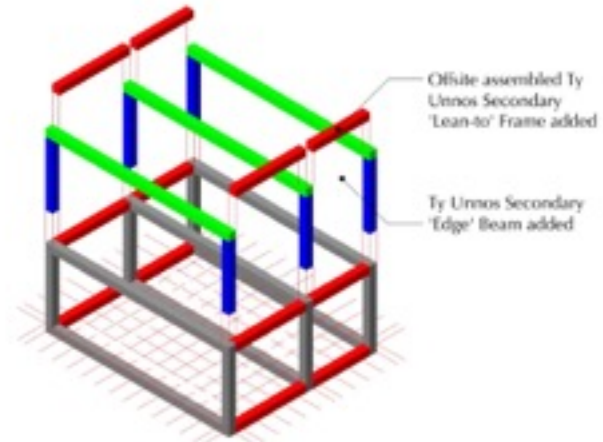
V 900.3 REDUCED WIDTH FRAME IN Y-AXIS As Current
SCALE 1:150 @ A3



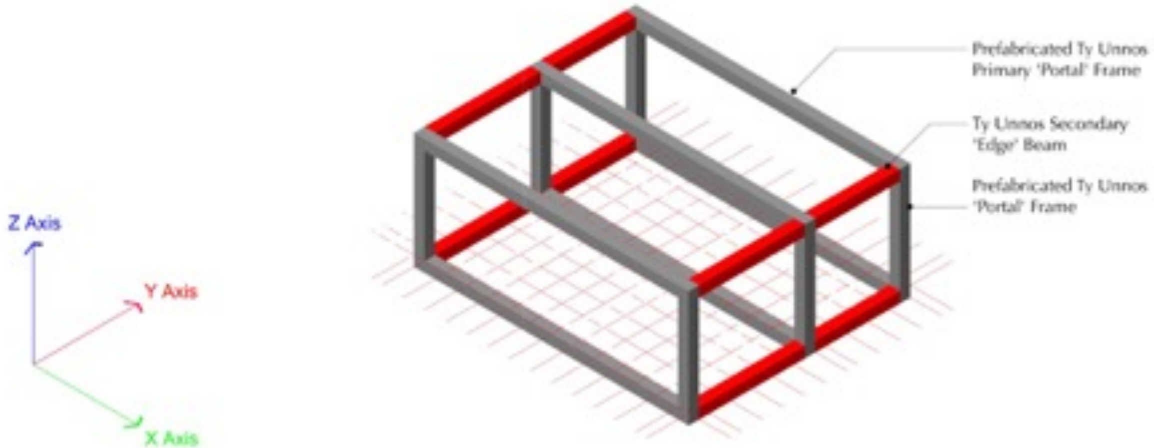
V 900.3 ADDITIONAL FRAME IN X-AXIS As Current
SCALE 1:150 @ A3



V 900.3 EXTENDED FRAME IN X-AXIS As Current
SCALE 1:150 @ A3



V 900.2 ADDITIONAL FRAME IN Z-AXIS As Current
SCALE 1:150 @ A3



V 900.1 BASIC FRAME ARRANGEMENT As Current
SCALE 1:100 @ A3

Current System : The Ty Unnos Post and Beam Frame / Connections

In adapting the box beam frame to provide a primary structure for the proposed system a primary concern is the build ability and adaptability of the structure particularly when reaching the end of it's initial life.

The Coed Cymru Show Stand provided a great opportunity to test the build ability and validity of the frame There has been contradictory feedback has been received regarding the value and build ability of the portal frame.

Kenton Jones suggests delivery of the portal frame preassembled is perhaps the greatest asset of the frame arrangement enabling the onsite works to be incredibly quick and with a great degree of control. The key to the accuracy of the build frame however relies entirely on the preparation of the foundation footings to ensure they are level prior to the delivery of the frame.

Matthew Jones of Maxiom argues that in his experience following the construction of the Pavilion, he would prefer components to come to site as independent elements rather than frames. The pavilion demonstrated the issue with misalignment of the frame

Primary Structure : Frame Connections

Current System : Frame Connections

The current Ty Unnos system uses a variety of frame connections which have been developed as specific solutions to individual problems on projects. These fall into two distinct categories for a structural perspective; rigid moment connections and pinned shear connections. Generally, Ty Unnos structures are formed from a series of rigid plane frames with secondary beams spanning between them. The connections in the plane frames are formed with rigid moment connections and all of the other connections are pinned shear connections.

Three of the most commonly used connections on recent projects are dscused in a bit more detail below.

Plywood “L”, “T” and “X” connections

These are currently the most commonly used Ty Unnos connections. They are formed by cutting “L”, “T” and “X” shapes out of plywood sheets and laminating them together to form rigid shapes which fit into the box beams. Depending on the required moment capacity of the connection some of the plywood layers can be replaced with softwood timber packing to reduce cost. Generally, these are able to resist moments up to 50-85% the box beam capacity depending on the geometry of the box beam. The table below shows the size of the plywood leg for different box beam sizes with capacities and approximate material costs.

The main disadvantages of this connection is the size, particularly for the larger beam sizes, and its weight and cost also have a large impact. Also due the length and depth of the connection within the box beams it significantly reduces their thermal performance.

Beam Reference	Plywood depth (mm)	Plywood width (mm)	Plywood length (mm)	Beam Moment Capacity	Connection Moment Capacity	Approximate Material Cost (£/leg)
TU - BB1	280	210	955	57.6	48.6	50.53
TU - BB2	280	130	955	43.4	22.7	31.29
TU - BB5	190	210	640	41.3	22.4	22.98
TU - BB10	130	130	430	13.0	9.1	6.54

Table 4.1 : Typical plywood L, T and X connections

Bolted Flitch Plate

This method has not been used to date as part of a Ty Unnos project but was developed for a complex frame arrangement. In this instance the connection was replaced with plywood “L” pieces because it was cheaper and easier to fabricate. In order to achieve the same performance as the plywood joints large numbers of bolts are required with long sections of steel plate.

Shear plate connection

This is a very simple connection consisting of a timber bearing plate screwed to the face of a box beam. The bottom flange of the joining box beam is notched back to allow it to be dropped onto the plate. It is severely limited by the number of screws required to resist applied shear loads. For smaller box beam sizes the capacity is limited by the number of screws and can be increased by increasing the depth of the plate beyond the bottom of the box beam to fit in more screws. For larger box beams, and smaller box beams with more screws, the capacity is limited by bearing of the box beam on the plate. This is the upper limit on the capacity of the connection as the plate thickness would have to be increased to improve it further.

Beam Reference	Plate depth (mm)	Plate width (mm)	Plate Thickness (mm)	No of Screws	Beam Shear Capacity	Approximate Material Cost (£/leg)
TU - BB1	350	210	70	35	55.14	9.83
TU - BB2	350	130	70	22	55.14	6.15
TU - BB5	260	210	70	35	41.26	9.10
TU - BB10	170	130	70	12	26.78	3.25
TU - BB10	330	130	70	22	26.78	4.40

Table 4.2 : Typical shear plate connections

Primary Structure : Frame Connections

The ability to use rigid moment connections as part of the Ty Unnos system is a distinct advantage as this is something not typically used in timber framing.

Two principle issues exist with these connections: the shear plate connection does not provide sufficient capacity and the plywood connection is expensive, heavy and a thermal bridge.

Initial Proposed System

No proposals for improving the connections were developed at the outset of this project. It was intended to undertake investigations to understand the requirements of these connections and propose possible solutions.

Investigation 4.1 : Shear connection requirements

This investigation was an analysis exercise to determine the minimum load bearing requirements for shear connections within Ty Unnos. There are three methods of transferring shear loads to and from a timber beam: side grain bearing, end grain bearing and via shear in mechanical fasteners. For a given load the first two of these define minimum required bearing areas and the third defines a minimum no of fixings. In order to make the connections as versatile as possible the beams allowable shear capacity has been used as a target capacity for connections. In practice this is more critical for the deeper beam sections to experience shears close to their capacities.

This shows the nature of the issues faced in providing a general shear connection to suit all beam sizes and loading conditions.

Beam Reference	Beam Shear Capacity (kN)	Side grain bearing area	End grain bearing area	No of Screws
TU - BB1	55.14	290x145	290x18	96
TU - BB2	55.14	210x200	210x25	96
TU - BB5	41.26	290x110	290x14	72
TU - BB10	26.78	210x95	210x13	47

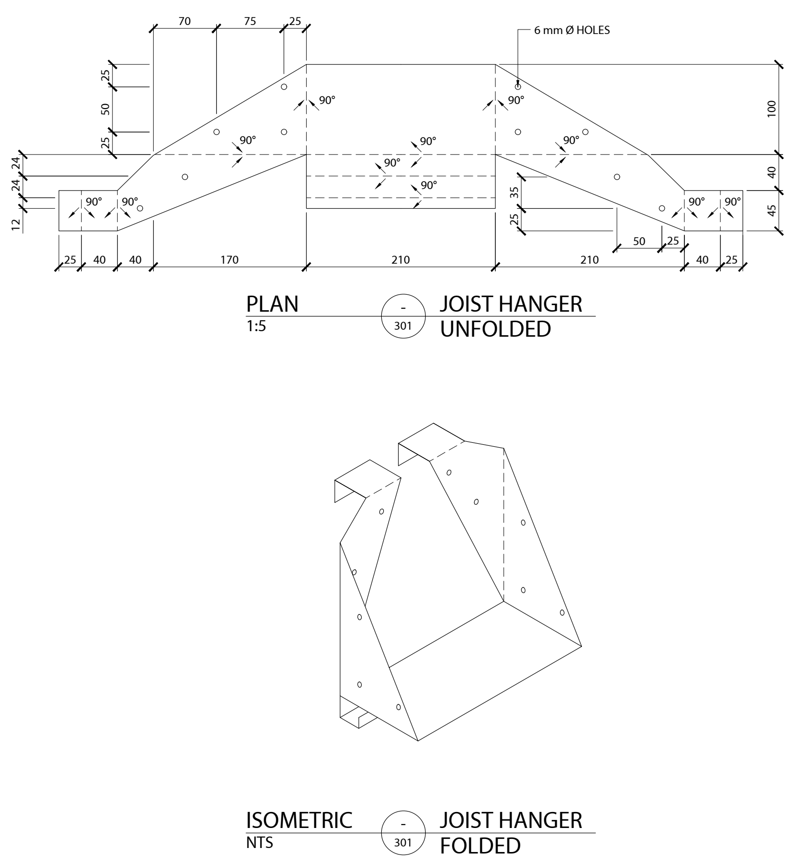
Table 4.3 : Shear connection requirements

Investigation 4.2 : Threaded bar connections

This investigation was an analytical examination of the potential to use threaded bars as a shear connection. This type of connection has been proposed a number of times throughout the development of Ty Unnos. It is formed by bonding threading rods into the corners of box beams which can then be passed through the joining beam and fastened with nuts and washers. As a shear connection the capacity of this connection type is not influenced by beam size, only by the size and number of bolts used. It also has the potential to be used as a rigid connection however the capacities are severely limited by the spacing of the bolts and the crushing strength of the timber. The main disadvantages of this connection type are that it has no allowance for tolerance and requires glued components within the box beam requiring certification.

Bolt No and Size	Maximum Bolt Embedment (mm)	Shear Capacity (kN)	Approximate Material Cost (£)
4 No M16	150	12.96	5.88
4 No M20	190	20.52	11.77
4 No M24	195	25.27	17.18

Table 4.4 : Threaded bar connectors



Proposed Ty Unnos pressed metal hangar

Beam Reference	Hanger Height (mm)	Hanger Length (mm)	Hanger Length (mm)	Bearing Width (mm)	Beam Shear Capacity (kN)	Connection Shear Capacity (kN)	Approximate Material Cost (£)
TU - BB1	420	150	12	2 x 70	55.14	55.14	31.66
TU - BB2	420	135	12	2 x 45	55.14	37.65	31.66
TU - BB5	330	110	10	2 x 70	41.26	40.96	26.38
TU - BB5	330	110	5	2 x 70	41.26	10.00	13.19
TU - BB10	210	100	11	2 x 45	26.78	26.78	12.22
TU - BB10	210	100	6.5	2 x 45	26.78	10.00	7.22

Table 4.5 : Proposed metal hanger geometry

Investigation 4.3 : Folded steel joist hanger

This Investigation was initially an analytical design exercise to determine the feasibility of a scaled up joint hanger but a trial manufacture was also undertaken. This is an adaptation of standard timber joist hanger technology. Typical joist hangers have allowable shear capacities in the order of 5kN and are made from folded thin gauge steel. They are generally reliant on nail fixings into the face of the supporting timber member. We have considered a large scale version of this to work with Ty Unnos box beams. This is based on using thicker gauge folded steel and bearing the hanger in a slot cut in the supporting beam rather than mechanical fixings.

This connection provides a very high shear capacity for most box beams, the exception being large narrow beams. It may be possible to reduce the required steel thicknesses by incorporating some mechanical fixings or some stiffeners in key locations.

Investigation 4.4 : Alternatives to rigid frame

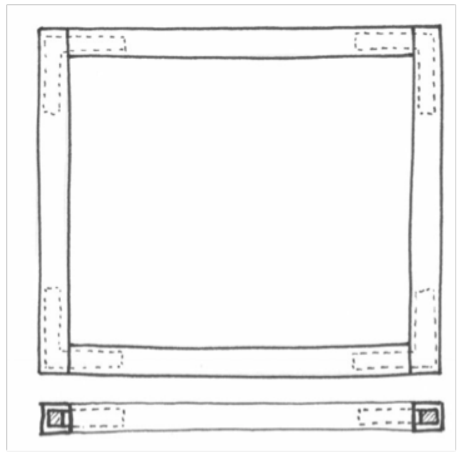
This investigation is a summary of the investigations into stability systems and the impact of the results on connection design. A number of alternatives to plane frames were proposed to resist laterally applied loads such as wind loads. These alternatives remove the need for rigid frame connections.

The current erecting sequence is reliant on erecting a series of plane rigid frames. This could still be achieved using a temporary connection, such as plywood or steel haunches. These could be re-used and could incorporate lifting locations.

The rigid connections could still be a useful part of the Ty Unnos system, for applications such as cantilevered balconies. Reducing the reliance on them would reduce the impact of their size, weight and cost and enables other solutions to be considered for reducing thermal bridging.

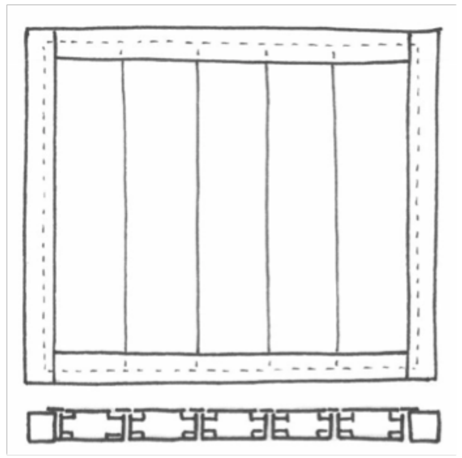
Beam Reference	Racking Capacity (characteristic) kN	Moment kNm
210 x 210 x40	4.28	2.57
270 x 210 x 40	6.88	4.13
360 x 210 x 40	10.31	6.19
420 x 210 x 70	18.33	11.0

Table 5.1 : Rigid frame racking capacities



Panel Type	With edge columns	Without edge columns
1200mm open	12.3	12.3
600mm closed	11.0	9.5

Table 5.2 : Diaphragm panel racking capacities



Current System : Structural Stability

Currently lateral stability is provided by a combination of rigid frames and diaphragm panels. Typically rigid frames are provided in the short span of the building with diaphragm panels in the long direction. This has developed because there are typically large openings in the short elevations of the buildings which do not leave sufficient space for diaphragm panels. It also fits with the typical errection sequence which involves bringing rigid frames to site as prefabricated elements.

Investigation 5.1 : Stability systems

3 options to provide lateral stability for the system have been considered. These have been tested numerically on the basis of a rectangular frame with clear opening size of 3x2.4m. These three options are discussed in detail below:

Base frame

This comparison is based on a base Ty Unnos frame formed from 4 No box beams, 2 No columns and 2 No beams. The connections between beams and columns are simple shear only connections. This is assumed to be formed from 210x210x40 box beams for all members. No infill has been assumed in the base frame so it could be empty or filled with wall panels or any size of opening.

Rigid frame

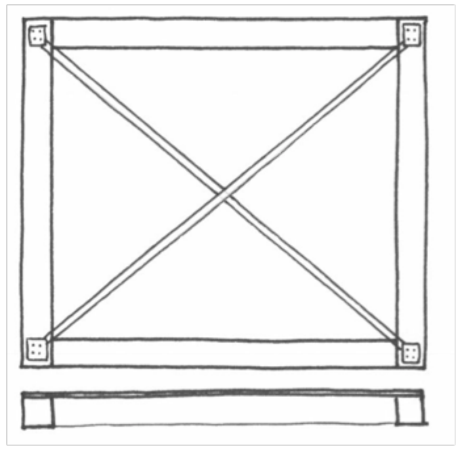
This is formed by replacing the connections between the beams and columns with rigid moment connections. The box beams have also been replaced with larger box beam sections.

This has racking capacities as follows for different box beam sizes, in each case the racking is limited by deflection criteria. The moments, which are the same for the beams, columns and connections are also shown for wind loads only, these would be influenced by the floor loading and frame centres.

It should be noted that in comparison with the other stability options the racking capacity of rigid frames does not change a significantly as the width of the frame increases.

No of M12 Coach Screws	Racking Capacity (kN)
2	6.7
4	13.4

Table 5.3 : Steel cross bracing racking capacities



Diaphragm Panels

This is formed by filling the opening in the frame with wall panels. This has been considered with 1200mm wide open panels (2No with 1 No 600mm wide) and 600mm wide closed panels (5 No). It is also possible to consider this as a 3m bay of panels in a larger framed opening, i.e. without connections to columns at the edges of the panels. This will put additional loads into the floor beams which have not been considered here

Racking capacities for these options are presented in the table below. In all cases panels with 5mm screws at 150mm centres on the perimeter have been considered. The 1200mm wide open panels require a steel plate connection to the construction below the panel (either another storey of racking panels or the foundations) or their capacities should be halved.

The capacity of the two panels types have been worked out using different methods from Eurocode 1995. The capacity of the wall panels increases significantly as the panel width increases.

Steel Cross Bracing

This is formed by fixing a pair of cross braced flats between the timber frame members. It is also possible to consider this as a 3m bay of bracing in a larger framed opening, i.e. without connections to columns at the edges of the panels. This will put additional loads into the floor beams which have not been considered here

The bracing which has been considered consist of 65x1.0mm flat steel diagonals with 2 or 4 No M12 coach screw connections in the corners.

The capacity of the wall panels increases significantly as the panel width increases.

Conclusions

These results show that rigid frames are the least efficient method of providing lateral stability, although they allow completely open frames. Steel bracing and diagram panels are roughly equivalent and could be used interchangeably.

Secondary Structure : Infill Panel

Initial prototype Ty Unnos buildings proposed and tested a range of alternative infill panel systems from expanded polystyrene based structurally insulated panels to closed off site fabricated panels capable of being insulated using natural and recycled insulations. However with the culmination of the PhD and TSB funded research studies, the development of a fully resolved panel system has somewhat stalled. Recent Ty Unnos buildings have employed a mixture of often bespoke solutions developed to be as cost effective as possible. Whilst these projects have delivered impressive on site results, it is generally considered that in order to extend the adaptability of Ty Unnos and specifically this project brief, a more advanced system needs to be considered.

Current system : Infill Panel System

The current infill comprises of two very different open panel solutions for vertical (walls) and horizontal (floor and roof) planes. Each of the panels is formed from a primary spanning element and sheathing. They are generally prefabricated with a standard width of 1200mm with non standard widths made to order to suit the proposed arrangement. One face of sheathing is applied in the workshop along with solid timber panel plates. On site panels are installed and a second layer of sheathing is added prior to building membranes and insulation if required. The majority of projects still employ pumped Warmcell insulation installed on site by a specialist sub-contractor.

The primary spanning elements were originally conceived as Ty Unnos ladder beams. These were initially developed as a joist replacement for spanning in floors, roofs and walls. The Type 01 ladder is the only ladder in continued manufacture. It is constructed from C16 graded softwood with 2 60x40 solid timber flanges and 130x40x210 rungs at 600mm centres. The rung to flange connection is formed with a glued tongue and grove joint and long screws. This has generally proved to be a poor structural element with restrictive spans, particularly under domestic floor loading. For this reason, they are typically only now used in wall and roof panels and are replaced with solid joists in floor panels.

Kenton Jones has typically employed plywood as the internal and external sheathing to panels. This is largely for cosmetic / quality reasons with alternative panel products such as OSB providing appropriate performance. In recent applications Kenton Jones has typically constructed floors with sheathing applied to both faces of the finished panels however wall and roof panels have been installed with sheathing just to the external face. The internal face is subsequently finished onsite with a taped and sealed vapour control membrane and timber battens to provide additional restraint to the pumped loose insulation.

Structural framing around openings is formed using solid timber trimmers on all four sides. Bespoke wall panels then span between the horizontal framing members. This system is simple and uses consistent detailing. However it results in very limited standardisation of infill panels as the inclusion of vertical trimmers to each structural opening disrupts regular building grids.

A number of projects have been delivered with this system and although limited feedback has been available to the research team, some consistent issues have been observed. These include;

- in order to accommodate non regular grids, non-rectangular areas and openings the complexity and range of panels sizes and shapes has been significant requiring greater input into fabrication information.
- this has included in some cases the fabrication of infill on site with loose joists and sheathing.
- Installation of Warmcell insulation on site, particularly where internal sheathing is omitted and reliance is placed on the membrane, has been highlighted as an issue causing significant spread of dust and issues with internal finishes.

Infill panels employed to date include open panels, OSB sheathed closed panels and closed panels with spruce laminated sheathing

Secondary Structure : Infill Panel

There are a number of concerns that need to be addressed in the development of a panel system which meets the performance criteria of the project brief;

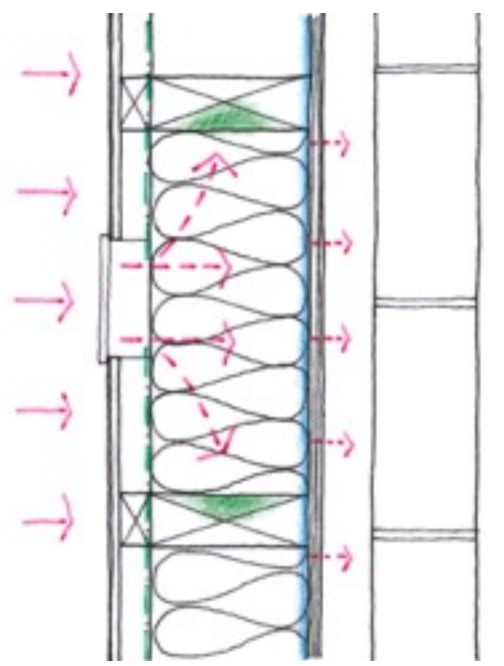
- the secondary structure has been designed to date primarily for use in domestic applications, the proposed applications will result in significantly higher load requirements,
- existing components need further consideration in order to meet the objectives of reuse-ability and recycle-ability which includes advancement of offsite fabrication,
- arrangement and detailed design of components need to target further standardisation to improve manufacturing and construction efficiencies,
- further investigation is required to consider the appropriateness of materials in meeting objectives for thermal performance, and breathability including insulations and sheathing products,
- buildability of components require further investigation with particular consideration given to the weight and onsite assembly method of components.

Initial Proposed System

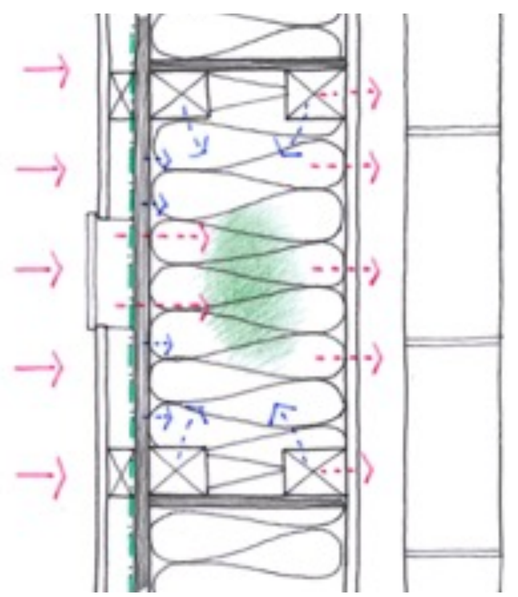
Investigations with concentrate on a system of closed or advanced panels. Previous panel systems have focused on the incorporation of ladder type assembled softwood components. The proposed panel system will set these components aside and instead employ ply web joists as the load bearing element of the system. Although the reliance on homegrown softwood is reduced, small section softwood will be employed to provide stability and connection in the panel and thus provide an essential element of the panel. The use of ply-web beams will dramatically improve the load bearing capacity of the panels, if compared with the existing ladder beam system. Joists will also provide a closed element to the panel edge enabling greater opportunity to advance offsite fabrication. Consideration will need to be given to the web material, fixing centres possible, use of structural adhesives and the size of the timber booms.

A number of alternative sheathing products will be tested internally and externally in order to address concerns with breathability and thermal bridging and improve the sustainable profile of the thermal infill component. Panels will be developed with recycled cellulose as the primary insulant however investigations will also consider the use of wood waste, cork and other natural insulation products.

There are a number of distinct advantages of closed panels for the Ty Unnos system. In terms of creating a demountable and re-useable building component it is critical as it significantly increases the proportion of the infill panel which is recoverable. It also increases the proportion of manufacture which can be undertaken in a factory environment and simplifies site erection, removing a sub-contract.



Plan of typical timber frame construction with external leaf of brick and internal service void



Plan of proposed 'breathable' system with outer brick leaf, Panelvent external sheathing, natural hygroscopic insulant, and OSB internal sheathing with service void.

Investigation 6.1 : Breathability

Moisture movement through the building fabric is a primary factor in the performance of timber frame construction and its subsequent failure. The 'breathability' of the building fabric is a factor that has perhaps not been afforded the necessary attention and consideration to date in the development of the Ty Unnos system. The current infill panel system makes use of panel products such as plywood and / or OSB, to provide sheathing to both the interior and exterior. Unless given due consideration, this can present a barrier to the passage of moisture leading to condensation within the thermal fabric which may lead to systematic failure.

The presence of moisture within the building fabric is a complex issue. For the development of a systemised approach to the structural and thermal envelope it is necessary to adopt a number of assumptions. This will enable investigations to focus on items that can be directly controlled within the core system components.

1. The outer surface of the fabric will be suitably detailed to ensure moisture penetration is not possible, either from precipitation or contact with the ground.
2. A ventilation strategy will ensure that indoor air quality and moisture levels are maintained within acceptable parameters.

As described by Neil May in *Breathability: The Key to Building Performance*, typical timber frame design in the UK employs a vapour control layer to the inside of the frame and a racking board commonly of OSB to the exterior. This system works in theory based on two assumptions, a) the vapour barrier remains intact for the life of the building, b) construction materials including insulations and timber are dry during assembly and enclosure i.e. have a moisture content below that which they will decay. In practice timber frame construction is allowed considerable exposure to rain during transport, storage and construction. Once VCL and OSB are installed onsite moisture within the fabric is largely trapped with limited potential for moisture to escape either to the interior or exterior. Trapped moisture remains within the wall buildup and is absorbed by hygroscopic materials including the timber frame and insulation materials, and / or is condensed on cold elements. In both cases, the presence of moisture is likely to cause decay, encourage the growth of moulds and reduce thermal resistivity.

In the Ty Unnos open panel system this common approach to timber frame construction has also been adopted. OSB or plywood sheets provide racking to the exterior of the structural Ty Unnos box beams, Ty Unnos ladder beams and solid section softwood studs and beams. To the interior, the open panel system has often been sheathed with plywood or OSB plus an airtightness membrane or vapour control layer (VCL). In some cases a VCL has been used on its own. This is subsequently infilled with loose Warmcel recycled newspaper insulation. In order to reduce the risk of the VCL being breached, a void is formed to the interior using 25mm or 38mm battens to create a zone for services to be distributed. This wall build up is considered cceptable when tested for interstitial condensation risk. And in some respects represents a better than common practice approach due to the provision of a service void and the improved vapour open and hygroscopic properties of natural insulations. However the system relies on the integrity and quality of installation of a fragile VCL and the moisture content of all materials to be fully controlled during construction.

It is not within the scope of this study to fully resolve and suitably test what is an extremely complicated area of building physics. However it is evident that for a timber frame system to be responsive to moisture it must;

- To the exterior of the timber frame - be vapour open,
- To the interior of the timber frame - be robustly vapour resistant and protected from the risk of penetration,
- To the infill insulation - be hygroscopic ensuring moisture is not concentrated within the hygroscopic timber structure.

Panel Type	Thickness	Typical Resistivity MNs/gm	Water Vapour Resistance MNs/g	Thermal Conductivity W/mK	Market Price Exc VAT £ / m2
13mm Panelvent	13mm		0.715	0.10	4.67
12mm Plywood	12mm	500	6	0.13	6.07
18mm Plywood	18mm	500	9	0.13	12.21
25mm Spruce cross-lam	25mm	~ 200	5	0.10	NA
Pavatex Isolair Sarking Board	20mm	5	0.45	0.045	8.47
OSB 3 18mm	18mm	216	3.88	0.13	6.25
Gypsum Plasterboard	12.5mm	60	0.75	0.19	1.90
Gypsum Plasterboard (Foil Backed)	12.5mm	4800	60	0.19	3.73
Gypsum Plaster	15mm	50	3.75		
Intello Membrane	0.4mm	3750	1.5	0.17	2.05

Table 6.1 : Comparative study of vapour resistivity of alternative materials

Alternative sheathing products

During the course of the R&D project a number of alternative approaches have been considered for internal and external sheathing. This has included the prototyping and testing of a Welsh spruce based cross laminated board. To date however investigations have failed to identify a Welsh timber product suitable for application in the system that is cost effective and provides sufficient structural stability.

The reliance subsequently remains on readily available panel products. There are a limited number of panel products available that are manufactured in the UK and an even more limited number of Welsh products. Kronospan are the largest wood panel producer in the UK, manufacturing a range of panel products in Chirk, North Wales. These include particleboard, MDF, HDF, T&G particleboard flooring, and melamine faced panels (both MDF and particleboard based) however a limited quantity of raw material is sourced within Wales.

A number of sheathing products are readily available which are specifically marketed for their improved 'breathability' i.e. response to vapour. These include;

- wood fibre based sheathing boards including Panelvent or Timbvent designed to replace OSB as an external sheathing product.
- wood fibre based rigid external insulation such as Pavatex or Steico designed as an insulation board in a variety of thickness with in some cases capacity to provide sarking.

In addition to readily available materials the project team are aware of a number of interesting ongoing R&D projects using Welsh products and processes to develop 'breathable' natural or recycled insulation products that may offer potential for collaboration, including;

- Wood fibre insulation using recycled fibres from MDF panel products,
- Loose insulation using wood waste shavings,
- Rigid insulation using wood waste fibres and shavings.

The table above illustrates the relative vapour resistance of the key readily available products. This illustrates the improved permeability of Panelvent and Pavatex Isolair over the existing utilised plywood and OSB.

It is intended therefore that manufacturing investigations will explore the use of alternative sheathing and insulation products. Investigations will assess the following key characteristics;

- Material cost,
- Ease of processing,
- Material waste,
- Robustness and quality.

Panel Type	Allowable Stress	Allowable Un-factored Live Load (effective span 600mm)		Modulus of Elasticity	Allowable Load for 1.6mm deflection (effective span 420mm)	
		UDL (kN/ m2)	Point Load (kN)		UDL (kN/m2)	Point Load (kN)
13mm Panelvent	17	4.37	1.31	2000	1.45	0.38
12mm Conifer Plywood	19	5.36	1.61	5037	4.53	1.19
18mm Conifer Plywood	19	11.32	3.40	5037	14.32	3.76
12mm Birch Plywood	33.2	9.39	2.82	6781	6.10	1.60
OSB 3 18mm	16.4	9.77	2.93	4930	14.63	3.84

Table 6.2 : Comparative study of load capacity of alternative sheathing materials

Investigation 6.2 : Sheathing

An investigation was undertaken to determine the suitability of different sheathing materials for use in floor, wall and roof panels. This assessed the load bearing capacity and deflection of different sheathing boards spanning 600mm under classroom, wind or roof loading to the methodology in BS EN 1995 for flexural members. The following table shows the results of this analysis for classroom loading, which is the most critical load case.

Findings

The calculations show that only 18mm Conifer plywood is suitable for floor applications in classrooms offices and workshops and that all of the boards are suitable for roof and wall applications. By Inspection 15mm Birch Plywood would also be suitable, however this would be considerably more expensive. The Panelvent will defect too much under the roof point load however given that it is to be used in conjunction with roof battens and a roof finish this seams reasonable.

Some benefit may be gained by undertaking load testing of panels to reduce the specification of the sheathing. This would involve loading a floor panel with point loads and UDLs and measuring relative deflection across the width. This is a relatively complex test (although TRADA have a piece of kit for this purpose) and the only likely benefit is reducing the plywood specification to 12mm conifer ply. Or 18mm OSB-3.

Table 3: Worst acceptable fabric parameters	
Roof	0.25 W/m².K
Wall	0.35 W/m².K
Floor	0.25 W/m².K
Windows, roof windows, rooflights curtain walling and pedestrian doors (1,2)	2.2 W/m².K
Vehicle access and similar large doors	1.5 W/m².K
High-usage entrance doors	3.5 W/m².K
Roof ventilators (inc. smoke vents)	3.5 W/m².K
Air permeability	10.0m³/h.m² at 50 Pa
Swimming pool basin	0.25 W/m².K

Notes:
(1) Excluding display windows and similar glazing. There is no limit on design flexibility for these exclusions but their impact on primary energy consumption and CO_2 emissions must be taken into account in the Criterion 1 calculations.
(2) In buildings with high internal heat gains, a less demanding area weighted average U-value for the glazing may be an appropriate way of reducing overall primary energy consumption CO_2 emissions and hence the BPEC and BER. If this case can be made, then the average U-value for windows can be relaxed from the values given above. However, values should be no worse than 2.7 W/m².K.

Worst acceptable fabric parameters from Approved Document Part L2A for new buildings other than dwellings

4.2.1 In order to demonstrate compliance with ***regulation 25C (b)***, the fabric performance values must be as good as or better than the worst acceptable values set out in Table 1.

Table 1 Worst acceptable fabric performance values	
External walls	0.21 W/m².K
Party walls	0.20 W/m².K
Floor	0.18 W/m².K
Roof	0.15 W/m².K
Windows, roof windows, glazed roof lights, curtain walling[2] and pedestrian doors	1.60 W/m².K
Air permeability [3]	10.00 m³/h.m² at 50 Pa

[2] The limiting value for curtain walling is an area-weighted average for the whole facade.
[3] Unless opting for alternative to air permeability testing on small sites which must be carried out in accordance with 3.3.2b(i) and 6.4.10b.

Worst acceptable fabric parameters from Approved Document Part L1A f or new dwellings

Type	Company 1			Company 2	Company 3	
	Type 01	Type 02	Type 03	Base Spec	Type 01	Type 02
Floor : U-Value W/(m2K)				0.18	0.25	0.22
Wall : U-Value W/(m2K)	0.35	0.32	0.33	0.18	0.32	0.26
Roof : U Value W/(m2K)	0.24	0.21	0.21	0.18	0.25	0.18

Table 6.3 : Comparison of thermal performance of existing marketed temporary building products

Investigation 6.3 : Insulation & Thermal Performance

The majority of projects to date have employed a 210mm structural depth to wall, floor and roof panels with Warmcell recycled cellulose insulation blown to fill the panel depth. In the development of proposals for the Royal Welsh Pavilion a number of investigations were undertaken to review thermal performance against current Building Regulations and consider insulation options.

Fig. … shows table 3 from the Welsh Government's Approved Document L2A (New Buildings other than dwellings), July 2014. These worst acceptable U-Values are higher than those required for new dwellings which can be seen in fig. These figures however offer relatively limited value in determining an appropriate performance requirement for the external fabric. Part L requires that new buildings meet or better a target CO2 emission rate generated through calculation to consider factors including fabric thermal performance, air tightness and mechanical and electrical services. Subsequently these U-values offer only an indication of the bare minimum.

A key objective of the Ty Unnos project from its inception has been to establish an ambitious approach to thermal performance and the building fabric adopting the approach of 'fabric first' whereby a high performance fabric ensures a flexible approach can be taken in the design and specification of mechanical systems and low and zero carbon technologies.

Table shows a brief analysis of standard U-values for a limited range of buildings that are offered as modular classrooms. This brief analysis illustrates earlier observations that the existing temporary building market offers limited thermal performance which is in some cases non compliant with current building regulations for new buildings. Each of the analysed products have a structurally insulated thermal fabric constituting laminated layers of sheet metal or timber based panels with rigid polymer insulation materials. These result in very compact wall build ups ranging between 80 and 200mm before finishes.

Using thermal modelling software a number of standard wall, floor and panel types have been modelled. These are indicative values and should be used as guidance only. Three panel thicknesses have been considered initially based on the most commonly used structural component depths of 210mm, 270mm and 290mm.

Panel Type	Overall Panel Dimensions	Insulation Type	Approximate Insulated Weight	U Value W/(m2K)
210mm Floor Panel	3000x600x228	Warmcell - Loose	79.52	0.18
270mm Floor Panel	3000x600x288	Warmcell - Loose	86.99	0.14
290mm Floor Panel	3000x600x308	Warmcell - Loose	89.48	0.13

Table 6.4 : U-values of alternative wall panel thicknesses

Panel Type	Overall Panel Dimensions	Insulation Type	Approximate Insulated Weight / kg	U Value W/(m2K)
210mm Wall Panel - Warmcell	2700x600x223	Warmcell - Loose	63.91	0.20
270mm Wall Panel - Warmcell	2700x600x283	Warmcell - Loose	70.62	0.15
270mm Wall Panel - Cork	2700x600x283	Cork - Loose	96.38	0.16
270mm Wall Panel - Earthwool	2700x600x283	Knauf Earthwool Roll	63.41	0.14
270mm Wall Panel - Thermafleece	2700x600x283	Thermafleece Batts	63.07	0.15
290mm Wall Panel - Warmcell	2700x600x303	Warmcell - Loose	72.86	0.14
290mm Wall Panel - Cork	2700x600x303	Cork - Loose	100.94	0.15
290mm Wall Panel - Earthwool	2700x600x303	Knauf Earthwool Roll	65.00	0.13
290mm Wall Panel - Thermafleece	2700x600x303	Thermafleece Batts	64.62	0.14

Table 6.5 : U-values of alternative floor panel thicknesses and insulations

Panel Type	Overall Panel Thickness	Insulation Type	Approximate Insulated Weight / kg	U Value W/(m2K)
210mm Roof Panel	3000x600x210	Warmcell - Loose	77.30	0.19
270mm Roof Panel	3000x600x270	Warmcell - Loose	84.76	0.15
290mm Roof Panel	3000x600x290	Warmcell - Loose	87.24	0.14

Table 6.6 : U-values of alternative roof panel thicknesses

Floor Panel - based on ; (Inside to Outside)

- 25mm Hardwood floor finish
- 1000 Gauge damp proof membrane
- 18mm Plywood
- Plyweb twin stud of 90x45mm softwood and 13mm Panelvent with full fill insulation as below
- 13mm Panelvent
- 150mm ventilation zone

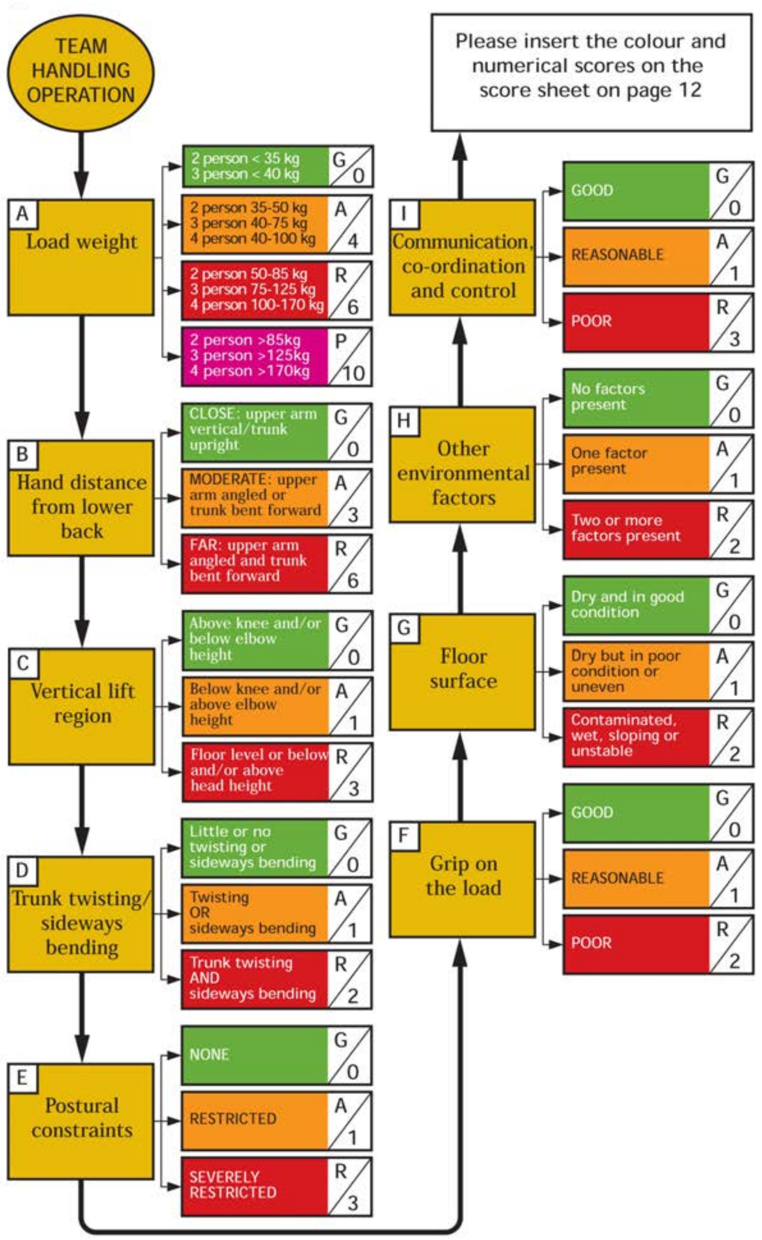
Wall based on ; (Outside to Inside)

- 13mm Panelvent
- Plyweb twin stud of 90x45mm softwood and 13mm Panelvent with full fill insulation as below
- 12mm Plywood
- Visqueen vapour barrier
- 25mm service duct

Roof based on ; (Outside to Inside)

- Membrane to receive roof finishes
- 25mm Plywood roof deck
- 25mm ventilation zone
- 13mm Panelvent
- Plyweb twin joist of 90x45mm softwood and 13mm Panelvent with full fill insulation as below
- 18mm Plywood
- Visqueen vapour barrier
- 25mm service duct
- 12mm Plywood / plasterboard internal finish

The results demonstrate a range of alternative specifications all of which will exceed the minimum fabric performance requirements. At a panel thickness of 210mm using Warmcell insulation, the fabric performance will exceed those of the existing market apart from Company 2, which employ a plywood based SIPS system.



G = GREEN - LOW LEVEL OF RISK
THE VULNERABILITY OF SPECIAL RISK GROUPS (EG PREGNANT WOMEN, YOUNG WORKERS ETC) SHOULD BE CONSIDERED WHERE APPROPRIATE.

A = AMBER - MEDIUM LEVEL OF RISK
EXAMINE TASKS CLOSELY

R = RED - HIGH LEVEL OF RISK - PROMPT ACTION NEEDED
THIS MAY EXPOSE A SIGNIFICANT PROPORTION OF THE WORKING POPULATION TO RISK OF INJURY.

P=PURPLE - VERY HIGH LEVEL OF RISK
SUCH OPERATIONS MAY REPRESENT A SERIOUS RISK OF INJURY AND SHOULD COME UNDER CLOSE SCRUTINY, PARTICULARLY WHEN THE ENTIRE WEIGHT OF THE LOAD IS SUPPORTED BY ONE PERSON

HSE Manual Handling Assessment Chart for assessing the risk associated with team handling operators

The existing system can be safely assembled using primarily manual handling support by lightweight plant demands. There are a number of key benefits associated with the assembly method that would perhaps be of even greater relevance for temporary building types as proposed.

For this assembly method to be maintained, weight is key concern in the design and specification of the system. The weight assessments shown above demonstrate that based on a 'standard' panel width of 600mm for walls, floors and roofs, panels weigh 60 - 80kg for a 210mm depth panel. If alternative insulations are compared Thermafleece, Earthwool, and Warmcell are comparative in weight between 63 - 70 kg. Cork insulation is however considerably heavier than the other three options at 97kg.

Based on *The Health and Safety Executive's, Manual Handling Assessment Charts,* a superficial assessment of the panel weights suggest that for a 3 person lift, the proposed 3m lengths with inclusion of 18mm plywood for floor and roof will place panels within the 'High Level of Risk' category. There are measures available to mitigate risk with additional people and lifting devices however it is evident that these panels are at, and perhaps beyond the limits of acceptable lifting weights.

Further Investigation -

- Cost differential between panel types.
- Build-ability exercise using insulated panels of varying thicknesses.

Max Span for 290mm deep panels	Load Type				
	Wind (walls) / m	Roof / m	Domestic / m	Office / m	Classroom / m
Glued Beam cts with conifer plywood webs @ 400mm	10.8	7.9	5.6	4.9	4.5
Glued Beam cts with conifer plywood webs @ 600mm	8.8	6.5	4.6	3.9	3.74
Nailed Beam with 4mm dia nails at 150mm cts and panelvent webs @ 400mm cts	3.9	2.53	1.6	N/A	N/A
Nailed Beam with 4mm dia nails at 150mm cts and panelvent webs @ 600mm cts	2.9	1.9	N/A	N/A	N/A
Nailed Beam with 4mm dia nails at 75mm cts and panelvent webs @ 400mm cts	7.2	4.0	2.3	1.7	
Nailed Beam with 4mm dia nails at 75mm cts and panelvent webs @ 600mm cts	4.8	3.9	1.7	1.4	

Table 6.7 : Maximum ply web beam spans

Investigation 6.4 : Ply Web Beams

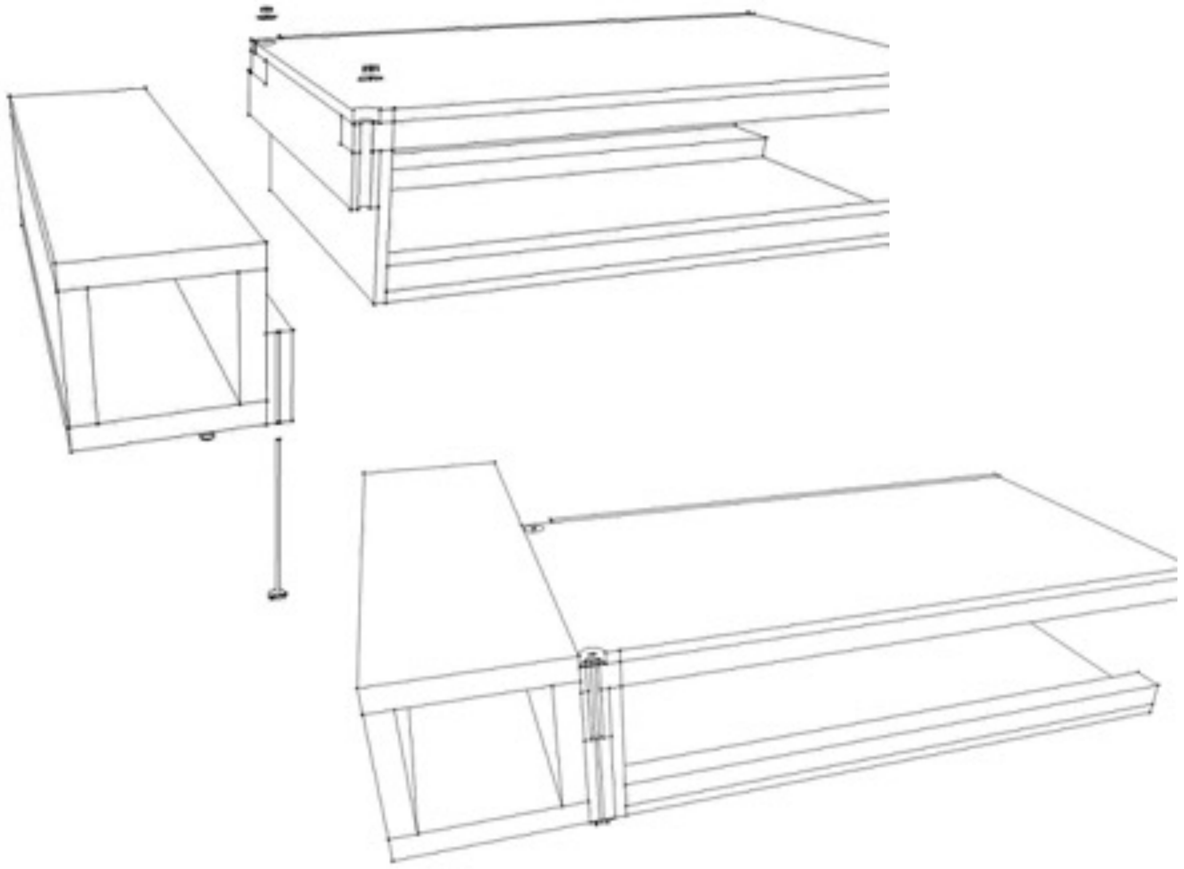
An investigation was undertaken to determine suitable web materials and fixing requirements for ply web beams. This assessed the spanning capacity of different ply web beam options under a range of loading configurations. This was done by calculation only based on the methodology in BS EN 1995 for designing mechanically jointed composite beams. The table below shows the results of this analysis.

This suggests that the most cost effective solution would be to use the glued beams for longer span floors, the nailed beams with nails at 150mm centres for the walls and short span roofs and the nailed beams with nails at 75mm centres for long span roofs and short span floors. It also generally shows that 600mm wide panels will be suitable for all applications although 400mm wide panels are significantly stronger.

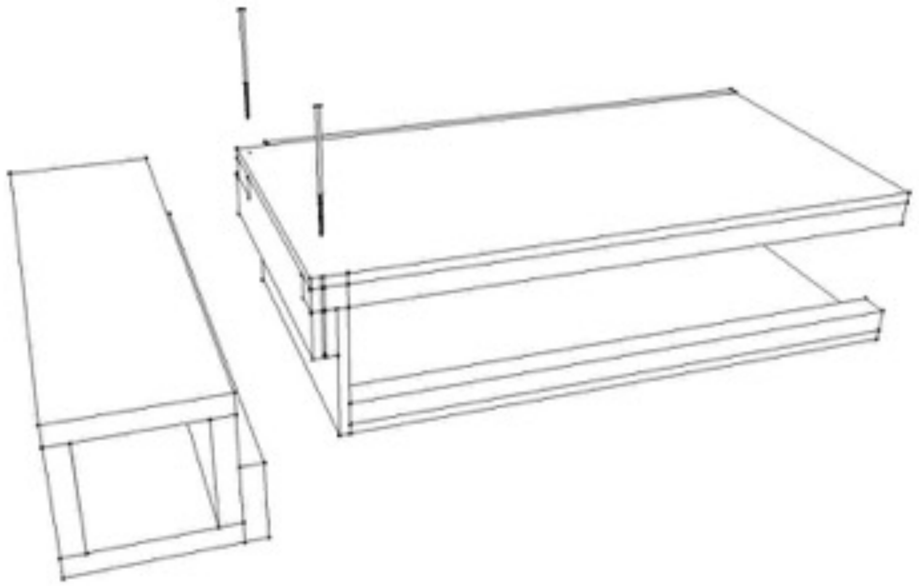
At the maximum span for "Glued Beams cts with conifer plywood webs @ 600mm" of 3.7m the largest box beam (420x290x70) would be able to span approximately 4.5m. This shows that these floor panels would not be the limiting factor in designing long span floors, ie the floor panels are strong enough to match the potential of the box beams.

This analysis does not take any account of composite action between the top and bottom sheathing and the ply web joists. Therefore there is more potential for this design which could be realised through further analysis or structural testing. Further testing would also be required to certify the glued ply web beams so it is recommended that whole panels are tested to verify and improve the analysis. Another worthwhile exercise would be to undertake a cost comparison of the glued and nailed beams to determine if it is more economical to use three different specifications or to have a one size fits all solution.

5 mins



Bolted connection between panel and beam in predrilled location holes.



Screw connections formed using SIPs screw fasteners with extended thread free shank

Investigation 6.5 : Connection to the Frame and between Panels

Different options have been considered for the connections to the frame however these are only initial concepts which will require further development. There are two drivers for the panel connections which are not compatible with each other. The aim of developing a demountable structure where the panels can be recovered with minimum damage to the frame or the panels requires the number of fixings to be minimised. Whereas the requirement for any racking / diaphragm capacity in the panels requires fixings between the panels and robust fixings to the frame.

One solution to this for the walls is to use alternative methods of stability such as steel cross bracing. However the general desire to reduce reliance on moment frames means that floor and roof diaphragm will be more important to span between separate lateral stability systems.

From this discussion there are two distinct functions for the panel connections, a fixing for loads applied perpendicular to the plane of the panel (ie panel in flexure) and a fixing for loads applied in the plane of the panel (ie panel in racking).

The former of these has been considered in two ways, a screwed connection and a bolted connection. Both of these use a solid timber wall plate fixed to the face of the box beam with screws. One of the timber studs then laps over and is fixed to the plate. For the screwed connection this is achieved with a long screw. This is a very simple connection but will cause damage to the timber plate and stud through repeated re-construction which will cause a reduction in load capacity. For the bolted connection this is achieved with a bolt in a large diameter hole in the stud and a clearance hole in the plate or into a threaded socket in the plate. The large diameter hole in the stud allows tolerance in the panel position, the bolt allows the panel to be re-constructed without any damage or wear to the connection. It is possible that this could be partially pre-assembled with the bolt fixed to the wall plate in the workshop.

Prototype 6.6 : Wall Infill Panel for the Coed Cymru Show Stand

The Coed Cymru Show Stand at the Royal Welsh Showground presented an opportunity to develop and test a prototype for an advanced panel system. Due to the restricted time scale for design and manufacture it was decided that the project would be used to apply and test a design for wall panels only, with the existing open panel used for floors and roof providing a comparative.

of a closed 270mm deep infill panel. was used for the walls. A closed 270mm deep infill panel system was developed to include;

- ply-web beams with panelvent webs fixed with nails at 300mm centres,
- an internal sheathing of plywood,
- an external sheathing of panelvent,
- top and bottom panel plates providing complete closure of the panel,
- and insulated with Warmcell offsite.

The primary aim of the investigation was to assess the efficiency of manufacture and the build ability and efficiency of on-site assembly. The research team were present on site during assembly and recorded observations and feedback via interviews with the manufacturer, contractor and labourers.

Observation 1 : For the panel connections the outer studs of the wall beams lapped with the box beam frame and were each fixed with 4 No large diameter screws. The panel to panel connection was formed with a cover strip fixed over the joint between adjacent panels with screws at 150mm centres. The contractor noted that the cover strips took a significant amount of time to install due to the large number of screws, he suggested that nails would be significantly faster.

Observation 2 : The end closure of the panels was formed with 40x40 timber battens and panelvent sheathing. The manufacturer of the panels complained that it was time consuming and fiddley to manufacture.

Installation of insulated closed wall infill panels to form 1800x2400mm structural opening for the Coed Cymru Show Stand

From top anticlockwise : Prototype 01, frame connection prototype 02, 3000x600mm panels, frame connection prototype 01,

Prototype 6.7 : Manufacturer Trial … Kenton Jones Joinery

Three panels were fabricated by Kenton Jones as a manufacturing trial. This included one panel with dictated geometry and two variations devised by Kenton Jones. Table … shows a comparison of the three different methods.

Panel 1 was constructed following prescribed geometry shown in drawing … , although a few modifications were made. The Pavatex panel closer and wall plate were replaced with panelvent and the insulation was omitted. The manufacturer noted that this panel contains a number of different components, i.e. both flanges are different lengths. In particular, the notches for the closure panels were noted as time consuming. Finally, it was noted that the 19mm dimeter holes for fixings were a difficult process, some of this related to the panelvent material and some to the thickness of material. This connection was not repeated on the other 2 panels types and is stated as having taken 20 minutes to process (5 minutes per hole x 4) the table above has been modified to reflect this. One of the objectives of this trial was to test the fixings into the pavatex end closures which has not been tested as this was swapped form panelvent.

Panel 2 was based on Kenton Jones standard method for constructing plywood boxes for cabinets. It is based on screwing together 18mm plywood with screws into the end grain of the plywood. This fixing method requires a high degree of accuracy to avoid splitting the plywood, both as a result of the small edge distance on the face and the end grain fixing. No splitting was visible on the trail panel suggesting all of the screws had been installed well. This type of construction has some significant drawbacks, it does not allow the inclusion of panelvent board to the outside face or to the webs, it would be very hard to justify structurally without testing and would not be able to be manufactured by less skilled carpenters.

Panel 3 was Kenton Jones suggestion for an improved version of panel 1. The length of the flanges was altered so all four were the same length, the panel closure was changed to plywood and the wall plate was solid timber. The main issue with this panel structurally is that the end of the spanning element is not directly connected to the wall plate. Thermally the solid timber wall late and plywood closure will also cause a significant cold bridge.

Findings

The three panels constructed by Kenton jones were load tested to determine their stiffness and ultimate moment capacity. This was done by loading the panels with concrete flagstones and measuring the defection. The panels were loaded in this manner with 10 flagstones (approx. 700 kg), deflection was measured for each additional flagstone. The load was then removed, deflection measured and then a 1000kg load was applied in one go and a final deflection reading taken.

Panel Type	Prototype 01	Prototype 02	Prototype 03
Front Sheathing (1 No)	13x474x3000 PV	18x600x2920 P	12x600x2884 P
Rear Sheathing (1 No)	12x600x2880 P	18x600x2920 P	12x600x2884 P
Webs (2 No)	13x245x2880 PV	18x600x2920 P	12x246x2884 P
Flanges (4 No)	2 No 40x90x3000 S 2 No 40x90x2790 S	None	40x90x2884 S
Sheathing Joints (1 No)	2 No 40x90x420 S 2 No 40x90x190 S	2 No 40x90x562 S 2 No 40x90x194 S	2 No 40x90x396 S 2 No 40x90x190 S
End Closure (2 No)	60x245x574 PV	18x234x562 P	18x600x270
Wall Plate (2 No)	60x145x600 PV	40x145x600 S	40x145x600 S
Mechanical Fixings	104 No 5x50 Screws 16 No 6x80 Screws	76 No 5x50 Screws 8 No 6x80 Screws	92 No 5x50 Screws 16 No 6x80 Screws
Glue	For End Closure Only	Each web glued to front and rear sheathing	None
Preparation Time	12 (32) min	10	19
Assembly Time	63 min	40	37
Total Time	75 (95) min	50	56

Table 6.8 :

Panel Type	Prototype 01	Prototype 02	Prototype 03
Deflection (mm)	7.7	2.4	6.2
At Load (Kg)	410	450	425
Stiffness EI (Nmm2)	2.8×10^{11}	10.1×10^{11}	3.6×10^{11}
Max Load (kg)	695 (failed at 1000)	1000	1000 (close to failure)
Moment Capacity (kNm)	5.1	7.4	7.4
Max Span (m)	2.52	3.03	3.03

Table 6.9 :

From the initial loading up to 450 kg a stiffness was calculated based on the change in load and change in deflection. From the maximum load sustained without failing a moment capacity was calculated, assuming no contribution form the self-weight of the panel. These two properties were then used to determine a maximum span under classroom loading. This assumed that he moment capacity calculated was a characteristic value. The results of this are shown in the table opposite.

It can be seen from these results that all three of the panels performed similarly although panel 2 performed the best and panel 1 the worst. However, it does suggest that the panels are capable of spanning significantly further than the numerical analysis suggested. The reduced moment capacity of panel 1 is most likely a result of the webs being panelvent instead of plywood. The increased stiffness of panel 2 is most likely because the webs of this panel were glued as well as screwed.

All of these panels were made with screw fixings between the web and flange at 300mm centres. The investigation into the structural capacity of the plyweb beams suggested that either glued web connections or fixings at 75mm centres should be used for such heavily loaded floors. Unfortunately, this suggests that the numerical model is not providing a good representation of the panel behaviour.

The above comments should be taken with some caution. The testing has only tested three panels under a single cycle of loading and none of the panels were identical. Therefore, we have not investigated the variation in performance which is likely to have a significant impact on the results.

Secondary Structure : Infill Panel

Panel Type	Prototype 01	Prototype 02
Panel Dimensions	2250 x 600 x 210	2250 x 600 x 210
Weight without Insulation (Kg)	46.2	45
Weight with Insulation	69	64.7

Table 6.10 : Installation weights for panels insulated using loose wood shavings.

Prototype 6.8 : Manufacturer Trial .... Towy Projects

In parallel with KJJ, Towy were also asked to consider the manufacture of a 600mm wide infill panel. Towy were asked to source Panelvent but were provided with a small supply of Pavatex Isolair rigid wood fibre board to form the closure detail and reduce thermal bridging through solid timber junctions. The original panel proposal shown in drawing ... was found to require quite considerable cutting of the Pavatex wood fibre board to form the end closure detail. Although easy to cut, the panel generated considerable amounts of wood waste and was found to clog up machines.

An alternative proposal was considered with a timber section replacing the outer lamination of wood fibre board. Although reducing the thermal break, the panel when manufactured was found to be considerably more robust to each end and easier to manufacture.

Following the completion of two prototype panels, a test was carried out to infill panels with wood shaving insulation provided by Plant Fibre Technologies. Based on weight and density calculations, shavings were installed by hand, with the inner sheathing of OSB removed to provide access to the full panel length. In order to achieve the required density, staged compaction was required with shavings loosely filled and packed down by hand. Once appropriate density was achieved, shavings remained slightly compressible and some concern remains regarding the settlement factor of the insulation when transported and in situ.

Findings

Initial concern in developing the design and specification of the panel was the strength of the Pavatex end closure panel at resisting the weight of insulation when vertical. Wood fibre board manufacturers provide very limited information regarding the tear out capacity of fixings and therefore it has been challenging to determine the capacity of fixings to retain boards. When fully insulated some bending of the closure panel was perceived however fixings held securely when lifted on end. Similar levels of distortion occurred to the Panelvent webs and sheathing which will need consideration when making allowance for construction tolerances.

Feedback from Towy was very positive regarding the design of the panel. There are a number of elements to the panel which require multiple manufacturing processes, and it is evident from both manufacturing studies that a simpler geometry panel will be easier to manufacture. However as a standard panel geometry Towy advised that a number of opportunities to 'jig' the manufacture of elements exist which would provide reduce manufacturing time and ensure consistency of quality.

When installed on a rigid sole plate, minor compression of the wood fibre board, in the region of 5% thickness, occurred which, if designed for, offers good opportunity to improve airtightness and reduce the need for petrochemical based foam fillers.

Panel Type	Panel width (mm)	Wall Height (clear) (m)	Max Opening width at any height (m)	Max Opening height at max width (m)
Nails at 150 mm	600	3.0	1.0	3.0
Nails at 150 mm	300	3.0	1.6	3.0
Nails at 150 mm	600	2.4	2.0	2.4
Nails at 150 mm	300	2.4	2.6	1.6
Nails at 75 mm	600	3.0	2.8	1.2
Nails at 75 mm	300	3.0	3.4	0.7

Investigation 6.9 : Framing openings

A design exercise was undertaken to determine a potential method for framing openings in external walls to accommodate doors and windows. This was based on using the wall panel either side of the opening to span vertically and to span panels above and below the opening horizontally to these panels. The same connection detailing can be used for the panel to panel joints by fixing a vertical plate to the edge of the panels.

This exercise showed that this method can accommodate openings up to 3.4m wide and up to the full wall height. The table below shows results for maximum opening width and height based on using full or half panels with nails at 150 or 75mm centres.

Conclusions & Further Work

The opportunity presented by this funding has been invaluable in the most recent developments of the Ty Unnos project. In conjunction with the construction of the Coed Cymru Show Stand, a broad range of investigations have been completed both as paper based exercises and manufacturing prototypes. The resultant findings have enabled considerable progress to be made that is relevant to both the objective of extending adaptability of the system components and improving efficiency for application to the original objective of housing. In addition to system development, the project has presented a positive opportunity to develop the supply chain, with Towy Projects, Maxiom, Pen Y Coed, and Gary Newman of ASPB and Plant Fibre Technology representing extremely exciting collaborations.

The portfolio of projects developed over the last 8 years using Ty Unnos components clearly demonstrates the adaptability of the system to alternative sectors to housing. However the system remains a bespoke method of building with limited market uptake. At the beginning of the project we set out with a broad range of objectives, however at its core was the ambition to develop the system components to become a standardised prefabricated whole building system that can offer a solution for permanent quality / temporary buildings for the three sectors of offices, light industrial and classrooms. It has not been possible to resolve a system which is ‘market ready’ however during the course of the project a range of prototypes have been developed that offer great promise for such a system. When applied to each of the building sectors considered, there are some extremely exciting opportunities to develop ‘products’ i.e. fully finished building types. Perhaps the most exciting of these is the application of autonomous classroom buildings or school extension buildings, of which the system and approach would appear to offer a range of ‘unique selling points’.

The report presents a broad spectrum of findings which in some cases are somewhat disparate however the key findings are as follows:

- The design process represents perhaps the greatest barrier to applicability and efficiency. Key to efficiency is the ability to influence design prior to the completion of statutory consent applications. A pattern book of designs could propose a wide range of standard building types and offer opportunity to standardise components, and maximise efficiencies. Where greater design input is required or desirable, design rules can be applied to bespoke designs to improve efficiency.
- A foundation system of lightweight removable proprietary pad foundations would appear to present great potential and compatibility with the permanent quality / temporary life agenda. Initial discussions with potential manufacturers suggest a ‘woodcrete’ or wood waste concrete version could be developed. However there are a range of foundation solutions that are compatible which require site specific information to determine appropriateness.
- As a large span structure, the system is most efficient for high load applications such as classrooms when applied to single storey spaces where large spans can be intermediately propped by substructure. Large span/ high load spaces at first floor will require significant structural zones which may undermine appropriateness if compared with other structural solutions however is still achievable.
- Primary frame connectors are an area of the system that require further development. The existing solid connector and shear plate solution presents some limitations when there is ambition to be flexible, adaptable and de-constructable. Alternative options have been considered and a lightweight hanger type solution appears to offer greater flexibility.

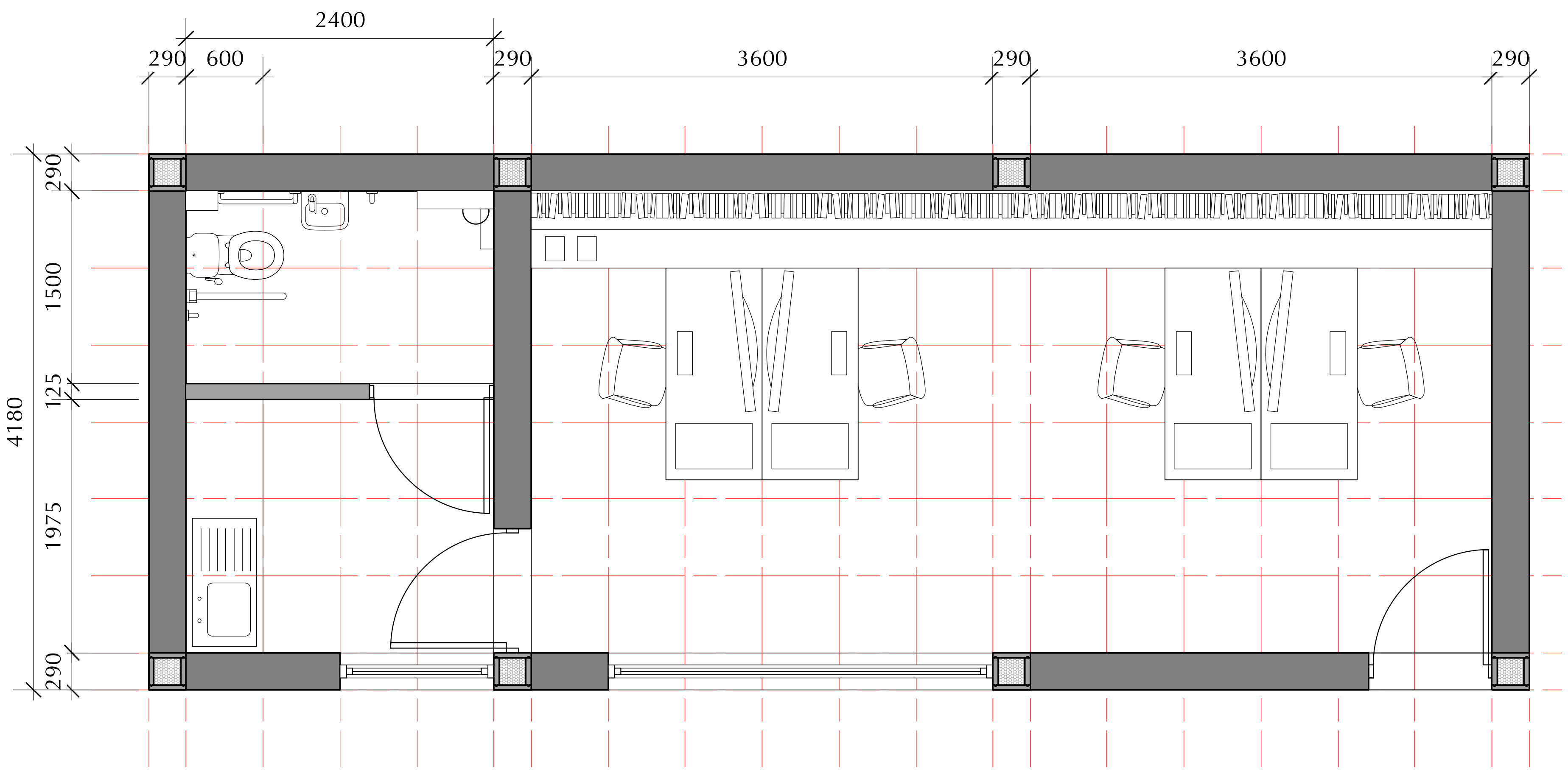
- Employing the panel system to provide all structural stability places additional demand on the panel design requiring larger and greater numbers of fixings. It is considered that an applied metal or panel racking system would enable greater flexibility and efficiency in the manufacture and construction of the system.
- A whole building advanced panel system is based on a 600mm grid in plan, section and elevation between primary structure. Panels are based on a 600mm panel size in order to be capable of manual handling however as insulation depth increases, weight of panels become prohibitive. Where manual handling isn't feasible and access doesn’t present an issue, larger panel components with a 1200mm width for example offer opportunity to reduce manufacturing cost. Where good access is available panels can be combined to form whole wall units for transport and improved on site assembly.
- Prototype panels have employed materials that are more capable of managing moisture build up including Panelvent sheathing and wood fibre board. Although investigations have been relatively limited numbers, the revised panel build up would appear to offer a cost effective solution with improved performance over previous panel types. The panel is more responsive than typical timber frame construction solution and is in line with best practice recommendations.
- Thermal performance of the components is adaptable and can be determined by budget and project specific brief. A minimum panel width of 210mm is structurally co-ordinated and will exceed current building regulations. Greater depths of panels can achieve a high performance envelope capable of achieving the higher levels of BREEAM and Passivhaus performance requirements.

The next stage of this investigation must apply these findings to the construction of a prototypical whole building. For any such

Proposed Further Work

- Prototype and test the assembly of a post and beam frame using hanger type connectors and lightweight temporary pad foundations.
- Cost exercise to review the cost differential of panel thickness and insulation type for a number of alternative building types.
- Prototype building assembly using revised panel system.
- Thermal modelling and performance testing of prototype buildings and whole wall components to review; inherent air tightness, thermal bridging, and interstitial condensation.
- A detailed review of education building standards to inform the developed design of standard classroom buildings.

Appendix A : Design Pattern Book



Gross Internal Floor Area : 36.5 sqm
Autonomous 4 person office with
welfare facilities

P 301.1 OFFICE TYPE 01 - Ground Floor Plan
SCALE 1:50 @ A3

0 1 2 3 4 M

DRAWING NO.
3415 P_301
REV.
/0000(GA)
Scale 1:50
Date June '15

DAVIES SUTTON
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Office Type 01
Ty Unnos Pattern Book

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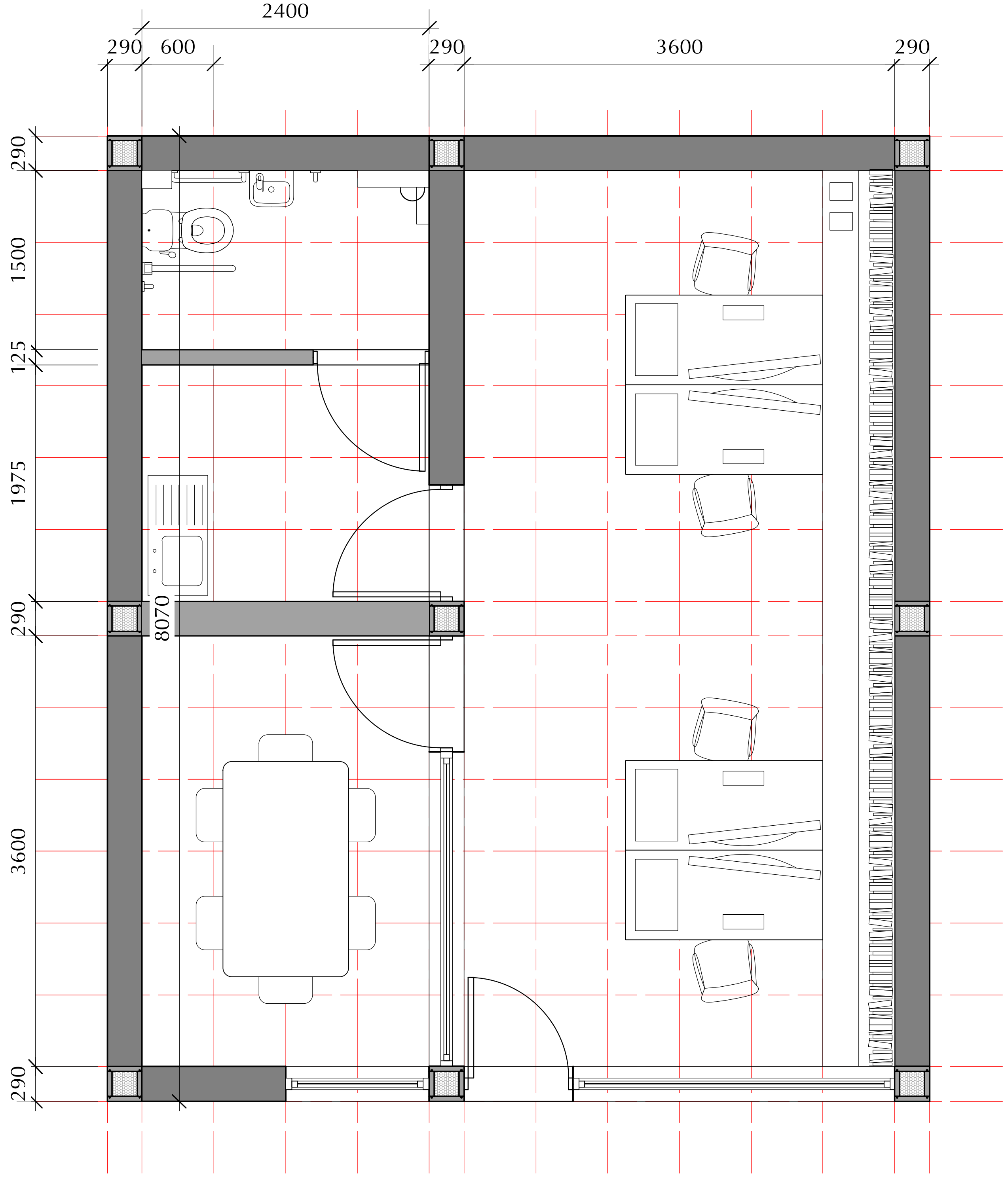
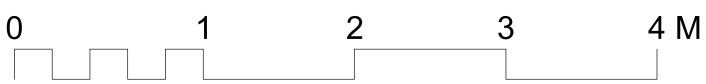
Coed Cymru



Gross Internal Floor Area : 47.0 sqm
Autonomous 4 person office with
welfare facilities and meeting room

P 302.1 OFFICE TYPE 02 - Ground Floor Plan
SCALE 1:50 @ A3



DRAWING NO.
3415 P_302
REV.
/0000(GA)
Scale 1:50
Date June '15

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Office Type 02
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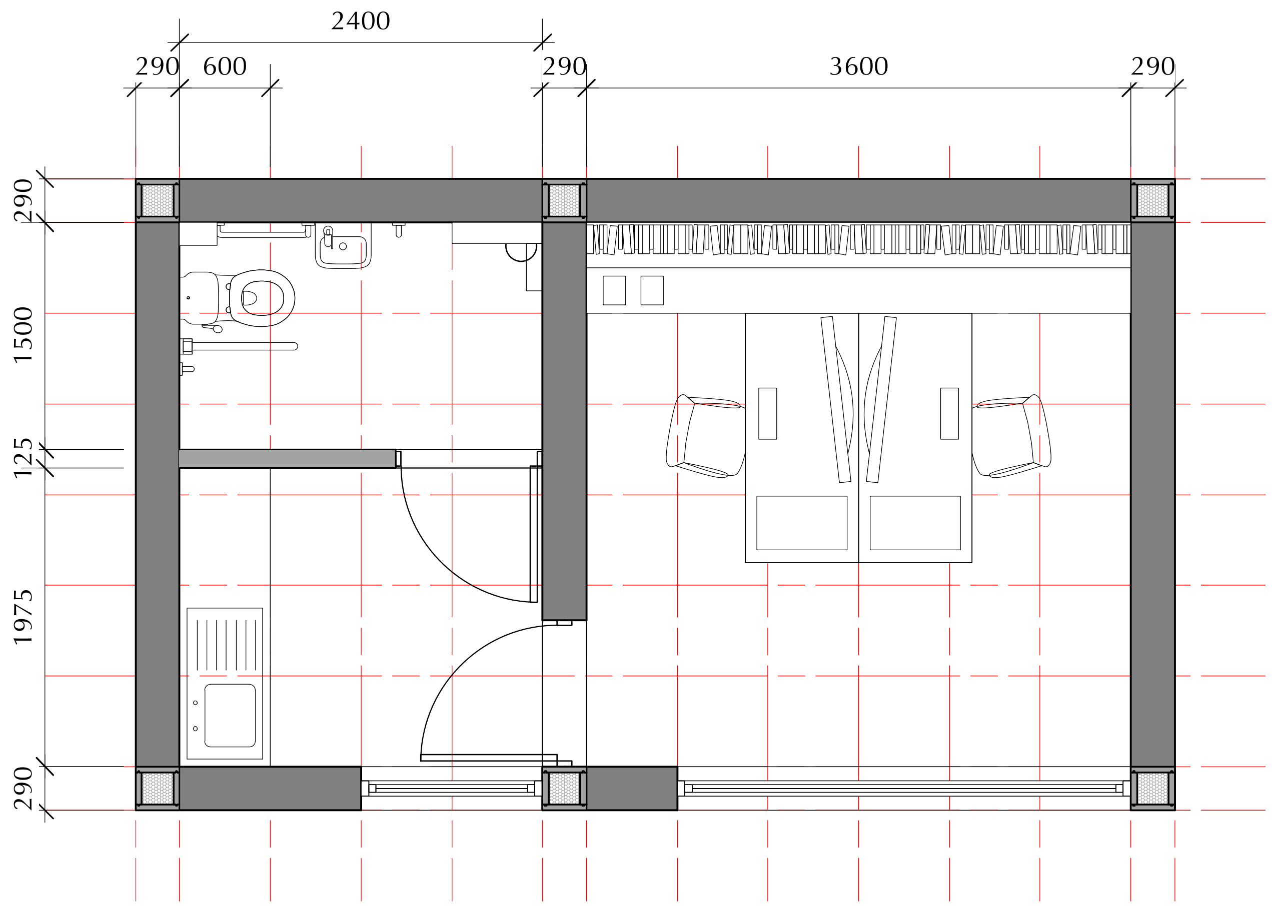

Gross Internal Floor Area : 22.5 sqm
Autonomous 2 person office with
welfare facilities

P 303.1 OFFICE TYPE 03 - Ground Floor Plan
SCALE 1:50 @ A3

0 1 2 3 4 M

DRAWING NO. 3415 P_303
REV. /0000(GA)
Scale 1:50
Date June '15

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Office Type 03
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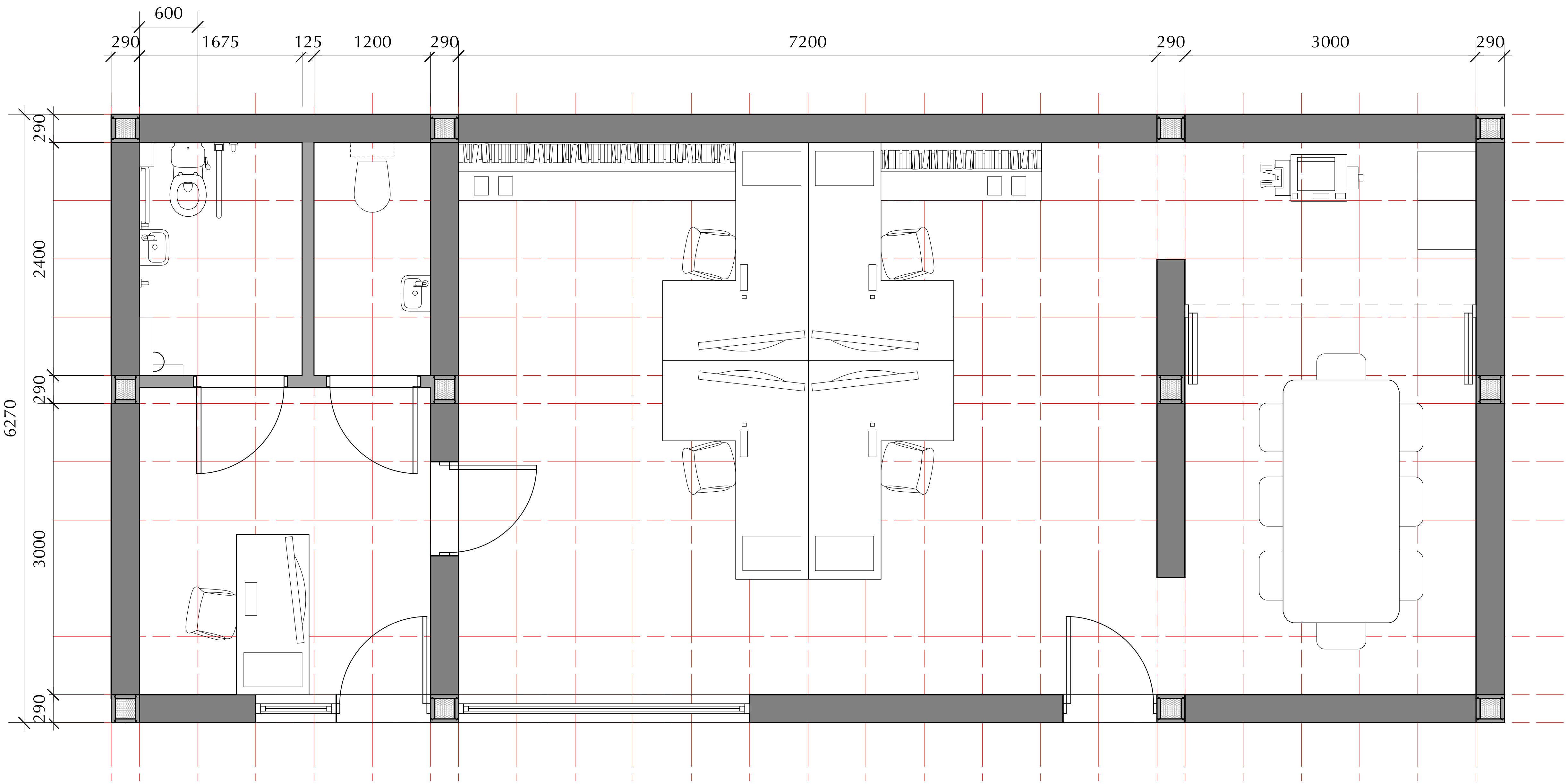
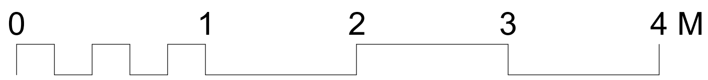


Gross Internal Floor Area : 78.5 sqm
Autonomous 5 person office with reception area, welfare facilities and meeting room



P 304.1 OFFICE TYPE 04 - Ground Floor Plan

SCALE 1:50 @ A3

DRAWING NO.
3415 P_304
REV.
/0000(GA)
Scale 1:50
Date June '15

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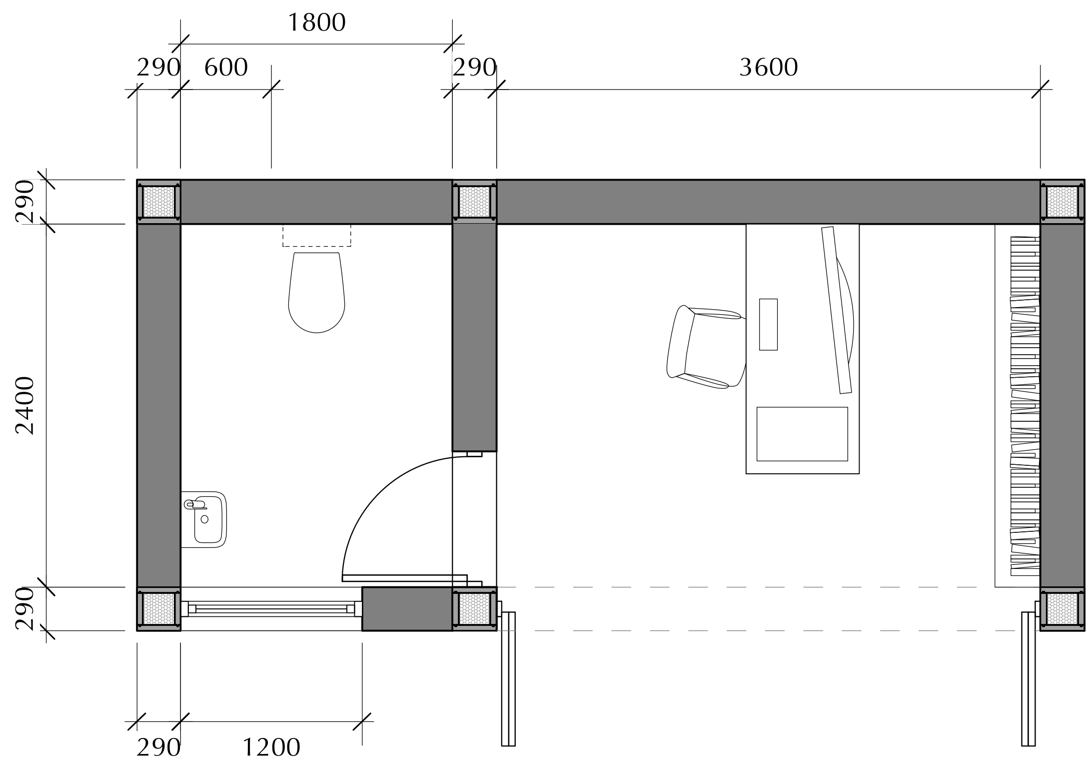

Gross Internal Floor Area : 13.6 sqm
Autonomous 1 person office with
accessible toilet

P 305.1 OFFICE TYPE 05 - Ground Floor Plan

SCALE 1:50 @ A3

0 1 2 3 4 M

DRAWING NO. 3415 P_305 REV. /0000(GA)

Scale 1:50 Date June '15

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Office Type 05
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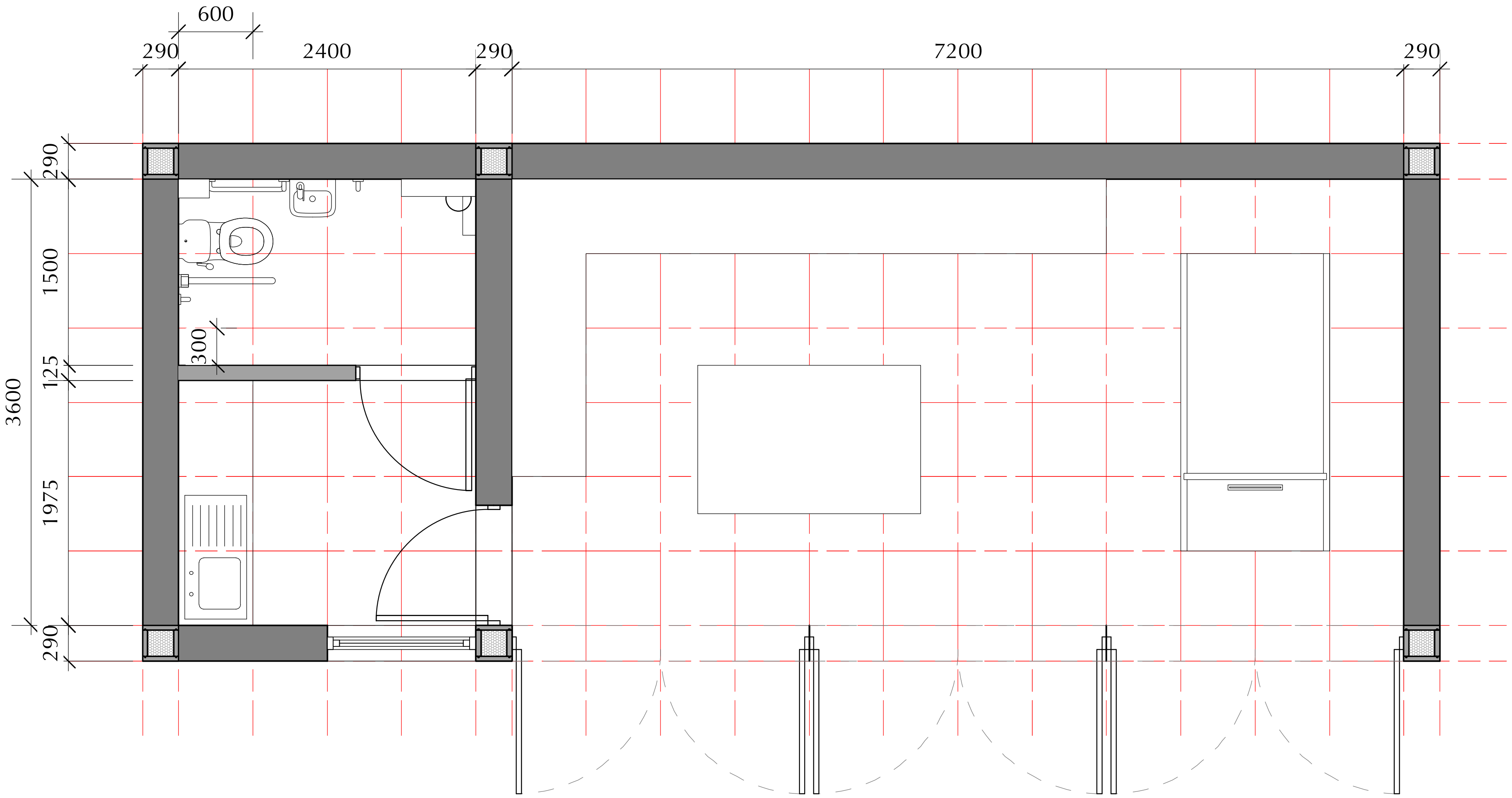

Gross Internal Floor Area : 35.5 sqm
Autonomous small workshop with
welfare facilities

P 311.1 LIGHT INDUSTRIAL TYPE 01 - Ground Floor Plan
SCALE 1:50 @ A3

0 1 2 3 4 M

DRAWING NO. 3415 P_311
REV. /0000(GA)
Scale 1:50
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Light Industrial Type 01
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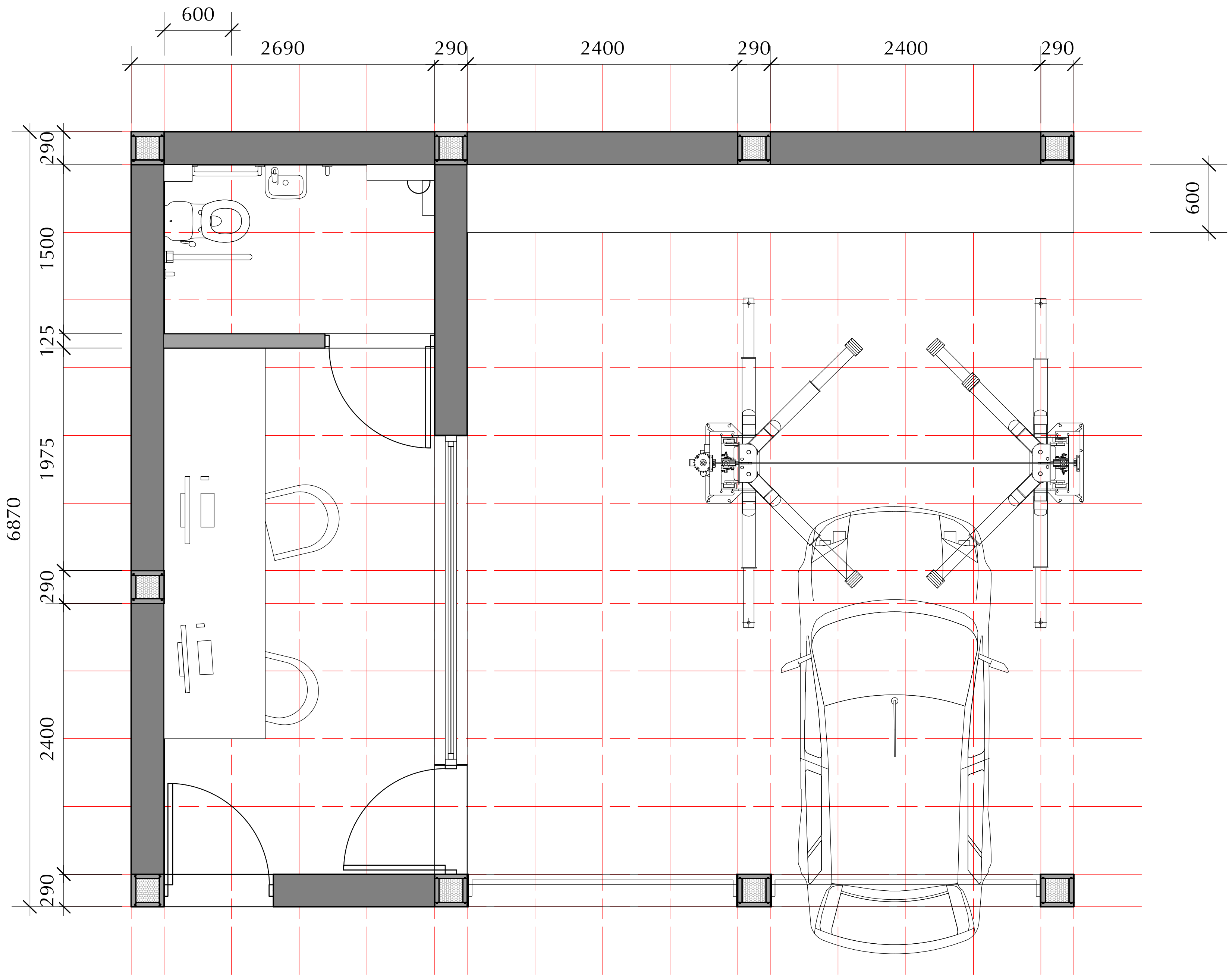

Gross Internal Floor Area : 50.5 sqm
Autonomous scalable workshop with
office and toilet

P 312.1 LIGHT INDUSTRIAL TYPE 02 - Ground Floor Plan
SCALE 1:50 @ A3

0 1 2 3 4 M

DRAWING NO. 3415 P_312 REV. /0000(GA)
Scale 1:50 Date June '15

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Light Industrial Type 02
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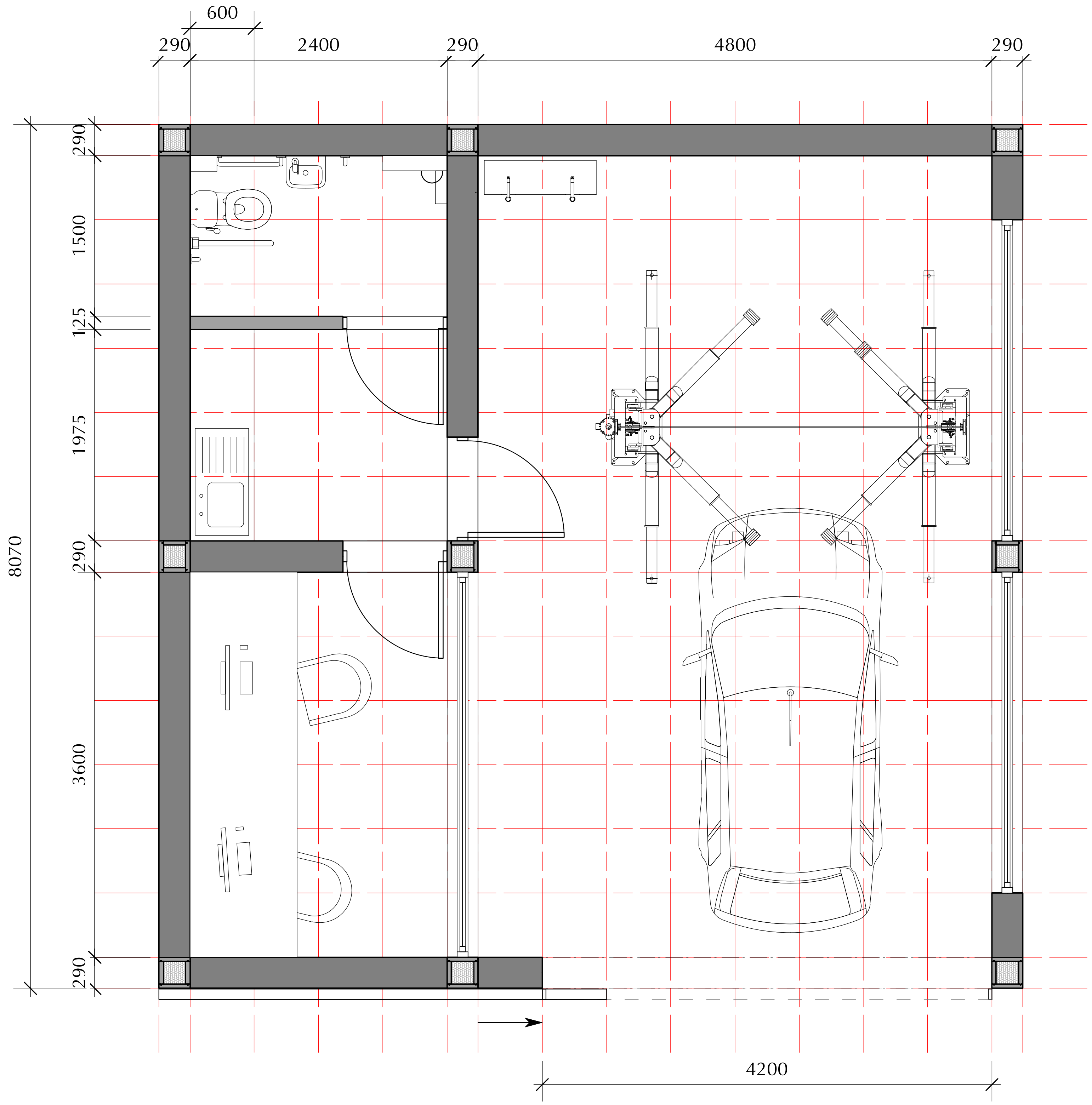

Gross Internal Floor Area : 56.0 sqm
Autonomous medium workshop with
office and welfare facilities

P 313.1 LIGHT INDUSTRIAL TYPE 03 - Ground Floor Plan

SCALE 1:50 @ A3

0 1 2 3 4 M

DRAWING NO. 3415 P_313 /0000(GA)

REV.

Scale 1:50

Date June '15

DAVIES SUTTON ARCHITECTS

Light Industrial Type 03
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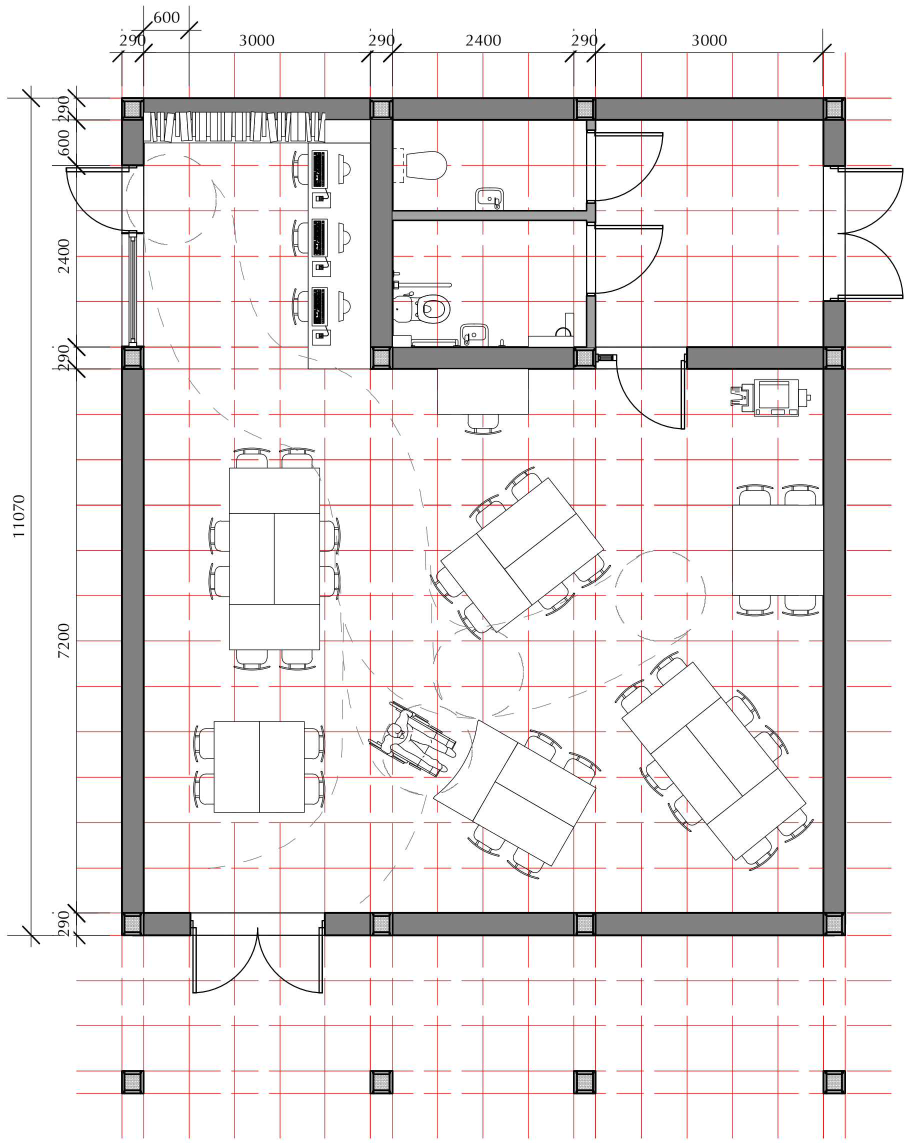

Gross Internal Floor Area : 94.0 sqm
Autonomous Single Classroom for 30 People
1 Unisex Accessible Toilet
1 Unisex Toilet
10 sqm Breakout Area

P 321.1 CLASSROOM TYPE 01 - Ground Floor Plan
SCALE 1:100 @ A3

0 1 2 3 4 5 M

DRAWING NO. 3415 P_321
REV. /0000(GA)
Scale 1:100
Date June '15

DAVIES SUTTON ARCHITECTS

Classroom Type 01
Ty Unnos Pattern Book

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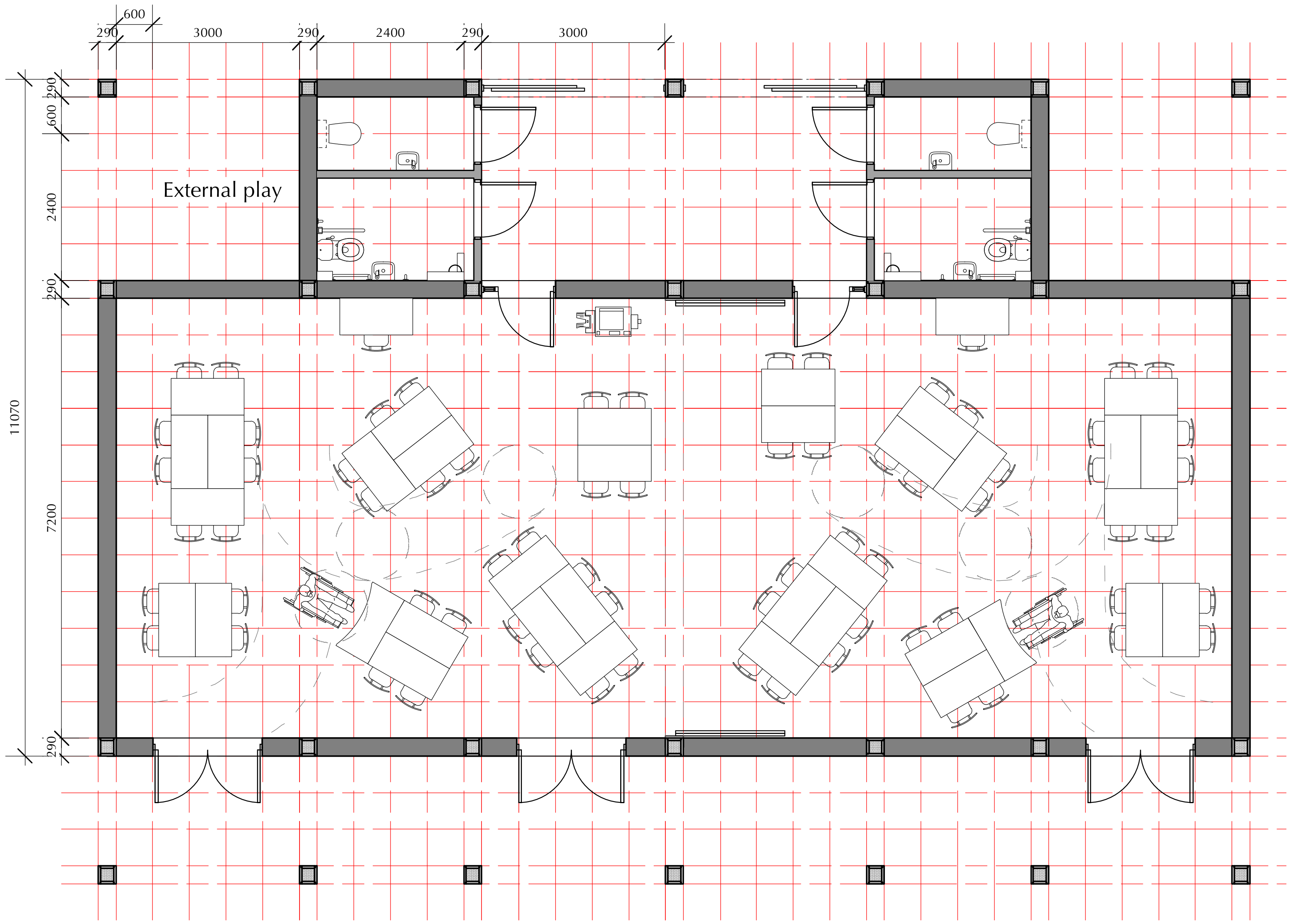
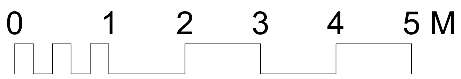


Gross Internal Floor Area : 170.0 sqm
Autonomous Double Classroom for 60 People
2 x Unisex Accessible Toilet
2 x Unisex Toilet
10 sqm Breakout Area

P 322.1 CLASSROOM TYPE 02 - Ground Floor Plan

SCALE 1:100 @ A3



DRAWING NO.
3415 P_322
REV.
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Scale 1:100
Date June '15

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Classroom Type 02
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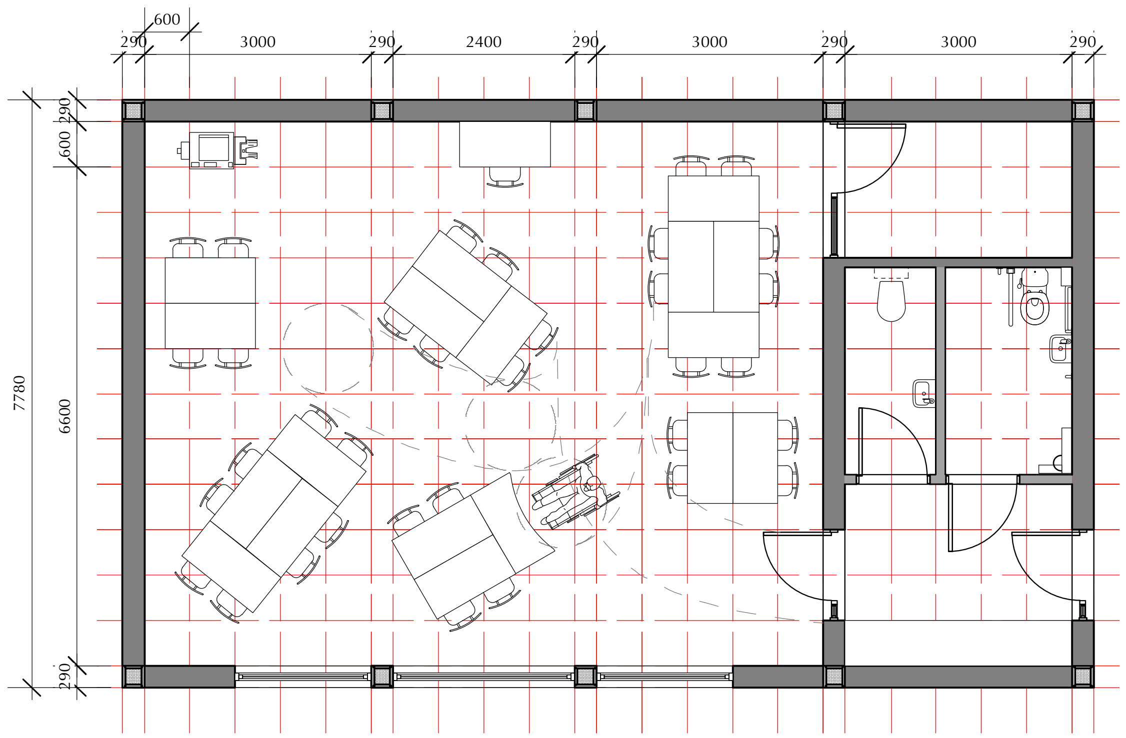
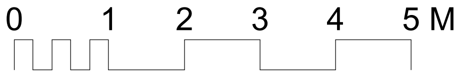


Gross Internal Floor Area : 88.5 sqm
Autonomous Single Classroom for 30 People
1 x Unisex Accessible Toilet
1 x Unisex Toilet
6 sqm Store

P 323.1 CLASSROOM TYPE 03 - Ground Floor Plan
SCALE 1:100 @ A3



DRAWING NO.
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REV.
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Scale 1:100
Date June '15

DAVIES SUTTON
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Classroom Type 03
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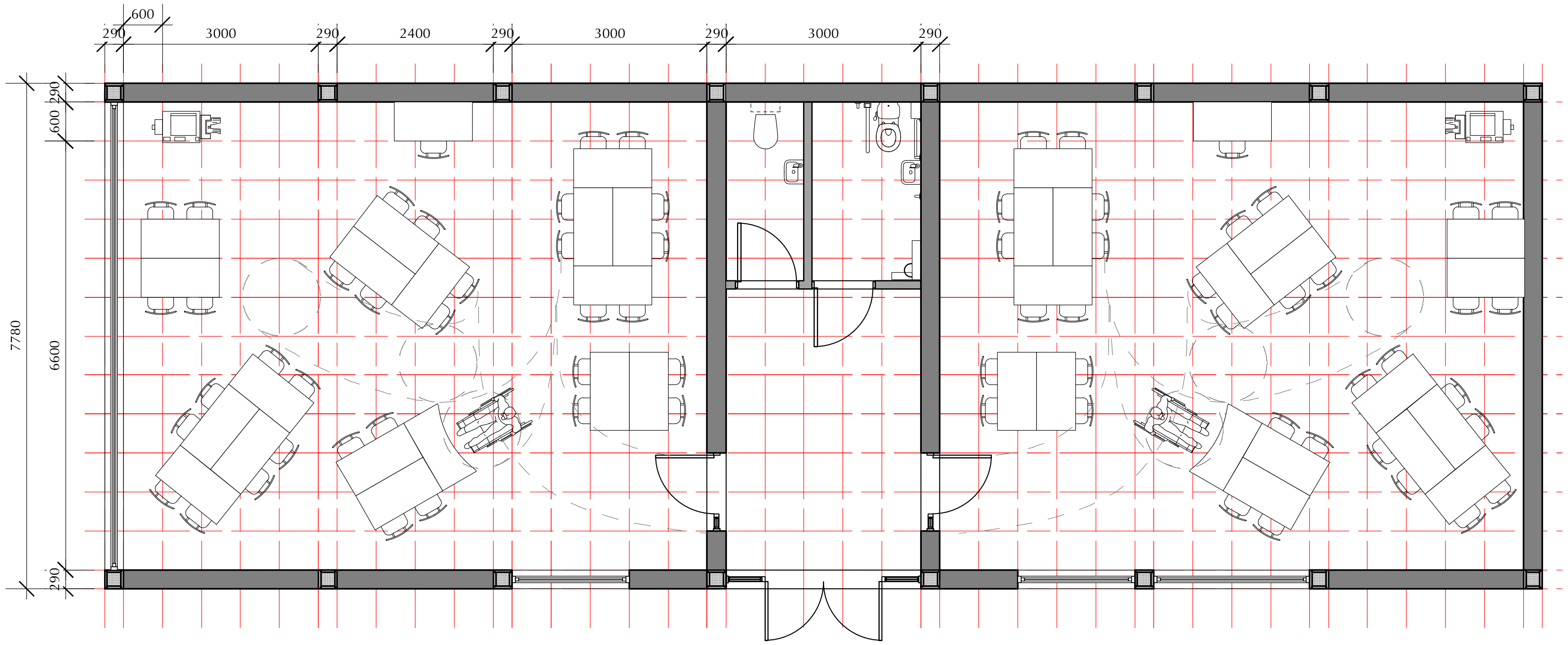

Gross Internal Floor Area : 155.0 sqm
Autonomous 2 x Single Classrooms for 30 People
1 x Unisex Accessible Toilet
1 x Unisex Toilet

P 324.1 CLASSROOM TYPE 04 - Ground Floor Plan
SCALE 1:100 @ A3

0 1 2 3 4 5 M

DRAWING NO. 3415 P_324
REV. /0000(GA)
Scale 1:100
Date June '15

DAVIES SUTTON ARCHITECTS

Classroom Type 04
Ty Unnos Pattern Book

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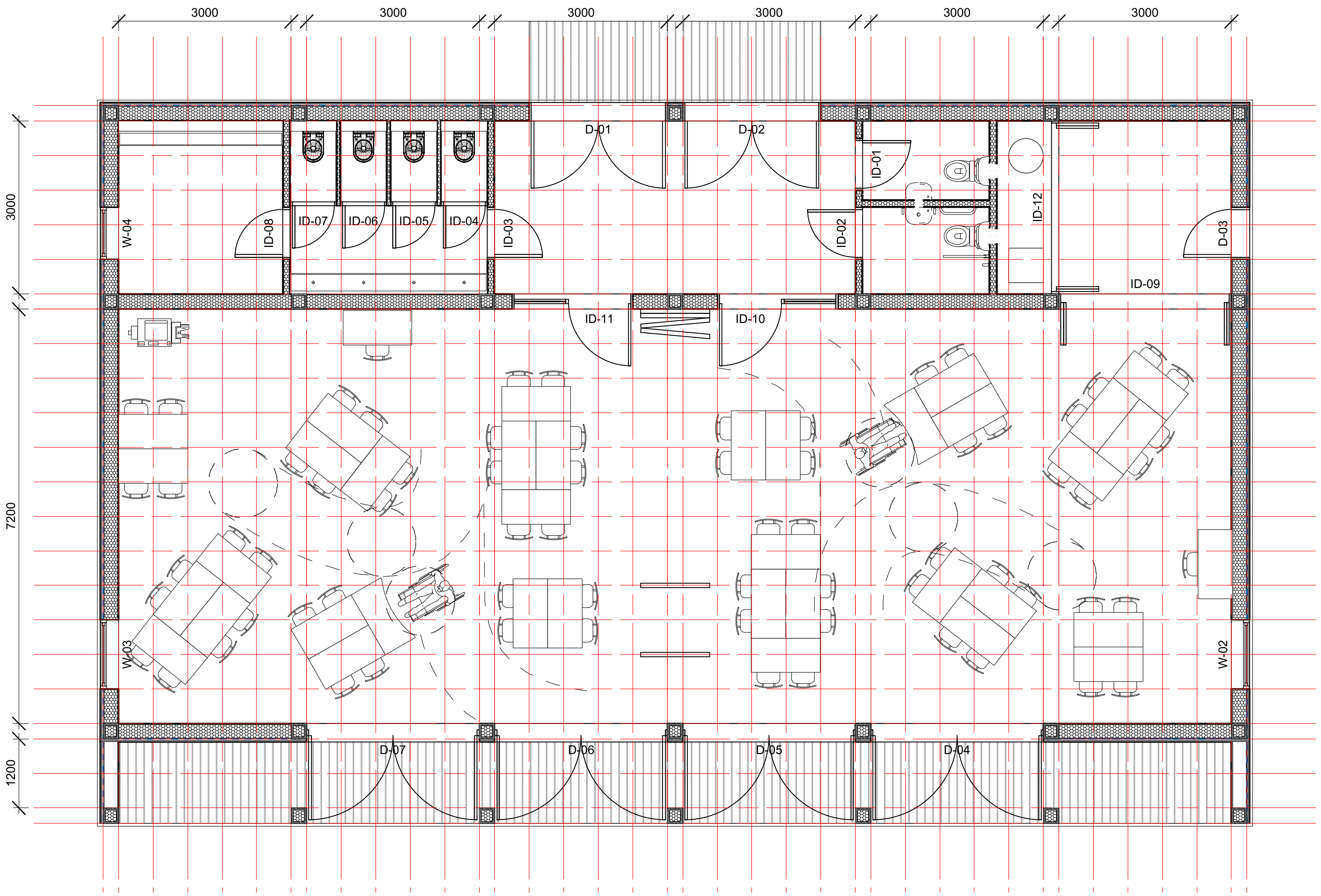

Gross Internal Floor Area : 202.5 sqm
Autonomous Double Classroom for 60 People
2 x Unisex Accessible Toilet
4 x Unisex Toilet
Urinals
12 sqm Store / Breakout Area

P 325.1 CLASSROOM TYPE 05 - Ground Floor Plan

SCALE 1:100 @ A3

0 1 2 3 4 5 M

DRAWING NO. 3415 P_325 /0000(GA) REV.

Scale 1:100 Date June '15

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Classroom Type 05
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Appendix B : Manufacturing Investigations